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DEFENSE CONTRACT
AN ANALYSIS OF ADAPTIVE RESPONS

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PREFACE

This Project RAND Memorandum is a result of RAND's continuing research on problems of efficiency in defense procurement and R&D management. It is related on the one hand to such studies as RM-2948-PR, Military Procurement and Contracting: An Economic Analysis, by Frederick T. Moore, June 1962, and on the other to such studies as RM-2482-PR, The Economics of Parallel R and D Efforts: A Sequential-Decision Analysis, by Richard R. Nelson, November 1959.

The present study focuses on the methods by which the Air Force and other government departments can keep development contract costs within reasonable bounds. It emphasizes the role of task uncertainty in the problem of contract cost control, and argues that in many situations the adaptive responses of the firm can vitiate the effects of contractual arrangements aimed at reducing costs through profit-sharing incentives. The conclusion of the analysis is that one of the most effective ways to strengthen cost controls is to reduce the task uncertainty associated with contract negotiations.

The author is a RAND consultant and a professor of economics at the University of Pennsylvania. For suggestions and helpful criticisms of a draft version of this study, he is grateful to many RAND staff members, particularly to E. Dews, T. K. Glennan, Jr., G. R. Hall, J. E. Hickey, F. T. Moore, R. R. Nelson, R. L. Perry, and L. Staszak.

SUMMARY

Good R&D management by a government department requires, among other things, effective organization, appropriate criteria for the allocation of resources, and appropriate contractual arrangements with development firms. The present study focuses on these contractual arrangements as they relate to the cost of development activities.

The market for defense R&D is imperfect and fails to provide a reliable mechanism by which the government can automatically secure performance at or near minimum cost. Cost control of work done under contract is therefore an important aim for defense R&D management.

In the past, two methods of cost control have been relied on by the government: (1) direct control through involvement in the firm's financial and technical operations, and (2) indirect control through incentives (usually profit-sharing incentives) provided in the development contract.

This Memorandum contends that both of these methods are inadequate to ensure low-cost performance. Because of the uncertainty surrounding development tasks as generally contracted for, a wide margin of discretionary choice is available to both government and contractor representatives. These opportunities for discretion (the author concludes) permit the contractor to develop adaptive responses which frequently render both direct and indirect controls ineffective. An alternative approach suggested here is to restructure the problem by partitioning the development task into technically separable components separately contracted for, and thereby to decrease uncertainty and increase the objectivity of cost negotiations and measures of performance. It is argued that proper limitation of tasks in sequence is necessary not only for good development strategy but also for good development contracting. The arguments for one reinforce the arguments for the other.

This Memorandum attempts to sharpen the issues by describing the incentives operating on both government and contractor representatives,

and by reinforcing description with an analytical model. Section I outlines the general nature of the problem. Sections II and III examine adaptive responses to cost plus fixed fee contracts and incentive fee contracts, respectively. These two sections, together with the analytical model given in Appendix B, suggest that, taken by itself, the manipulation of rewards at the margin has little prospect of substantially improving cost performance in development contracts. Section IV provides some tentative suggestions toward the restructuring of the contract task as an alternative method of cost control. Section V outlines the conclusions of the study.

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The use of direct controls (auditing, renegotiation, and so on) and indirect controls (manipulating rewards, say, through various incentive fee arrangements) have been the principal means emphasized in previous studies of defense contracting, for inducing the desired performance in the defense industry.* The possibility of redefining the task has been generally neglected as a means of affecting performance. Scherer, for example,** does not even consider task definition as a means of influencing contractor behavior.

> [Since] the automatic guides and restraints provided by the market's "invisible hand" are absent..., the government must deliberately structure its relations with contractors in such a way as to assure successful weapons program execution.
>
> It has two main ways of doing this. One is through controls -- direct participation in the contractor's internal operations through technical and financial administration and decision making.... The other way is the incentives approach.

This neglect seems to the present author to be responsible for many of the difficulties experienced in attempts to remedy the observed defects of defense contracting.

The position taken in this Memorandum is that (for reasons developed in Sections II and III) the internal-control and contractual-incentive approaches are generally insufficient to produce the desired performance result. Given the types of objectives operative among defense contractors and the Armed Services, a fundamental restructuring of the task is first necessary.

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*This Memorandum distinguishes studies of contractual arrangements from studies of R&D strategy. The analysis is restricted to the former and our comments are similarly circumscribed.

**Frederick M. Scherer, The Weapons Acquisition Process: Economic Incentives, Boston, Mass., 1964, p. 2.

"Performance" can be analyzed in terms of efficiency, equity, stability, and technical progress. In defense procurement, however, technical progress is frequently inseparable from the commodity for sale. It is therefore assumed that progressiveness objectives are being attended to, and the study focuses on the costs of achieving these objectives rather than progressiveness as such. Equity is mainly dependent on income distribution considerations. Because direct controls tend to impose tight reins on profits and conspicuous expenditure items (salaries, emoluments, and so on*), equity performance, at least in a gross sense, will be assumed to be satisfactory. Thus, the present study emphasizes the efficiency and stability objectives of performance.

Unsatisfactory efficiency performance has been noted by Peck and Scherer** as well as by previous investigators.*** Although some of the reasons why efficiency performance has been unsatisfactory have gone undetected, at this point we merely accept the judgment that the efficiency goal requires attention and leave the reasons why this might be so to subsequent analysis.

The stability performance of the defense industry has received less explicit attention, although it has often been observed that the variability in sales and employment within individual firms over time has seemed unnecessarily high, considering the overall stability of expenditures on weapons and space development and procurement. However, the data have never been organized in a form that would aid in judging the stability of sales and employment. In order to make the judgment, a linear trend line has been fitted to the annual sales and employment histories of the principal firms in the aerospace industry and the industry aggregate, as well as four other industries for the period 1954-1963. The average absolute residuals were then calculated and divided by the mean level of activity. Thus, the measure of

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*Ibid., p. 205.

**See Merton J. Peck and Frederick M. Scherer, The Weapons Acquisition Process: An Economic Analysis, Boston, Mass., 1964, pp. 593-594, and Scherer, op. cit., pp. 314-315.

***For example, John Perry Miller, Pricing of Military Procurements, New Haven, Conn., 1949.

variability is average absolute residual about the trend line as a percentage of the mean level of activity over the interval.* The results are reported in Appendix A and are summarized in Table 1.

As is quickly apparent from Table 1, both the sales variability and the employment variability for the principal firms in the aerospace industry were higher than the corresponding variabilities among the principal firms in the four other industries. However, the amount of sales variability for the aerospace industry taken as a whole was also higher than in every industry other than steel, and the amount of employment variability in the aerospace industry was higher than in each of the other industries for which this figure could be obtained. If the level of industry variability is taken as indicative of the level of "natural" variability imposed on the firms in the industry, then firm variability should not be considered excessive unless some correction is made for the amount of industry variability experienced.

As is shown in Appendix A, it is possible to devise a measure by which the total amount of firm variability can be corrected for an industry effect. It is necessary, however, to take a complete census of the entire industry in order to make the separation. The cost of doing this would be prohibitive in relation to the needs of the present study. As an approximate correction for the industry effect, we use the ratio $\frac{\bar{x} - T}{\sigma}$, where $\bar{x}$ is the average firm variability, T is the industry variability, and σ is the standard deviation of firm variability. On this criterion, as the last column in Table 1 reveals, the aerospace industry displays the worst performance (greatest variability) of any of the five industries studied, although electrical equipment is a close second.

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*A linear trend is a rough approximation. For the short interval that we are concerned with here, it provided a generally close fit. It is of some interest to note that my correction for trend and analysis of variability as the average absolute residual as a percentage of the mean is close to the technique employed by C. E. Ferguson in his study of employment stability in A Macroeconomic Theory of Workable Competition, Durham, North Carolina, 1964, pp. 94-102.

Table 1

VARIATIONS ABOUT TREND, SALES, AND EMPLOYMENT, PRINCIPAL FIRMS AND INDUSTRY TOTALS, 1954-1963

Industry	Number of Firms in Sample	Average Absolute Residual as a Percentage of Mean: Principal Firms: Average ($\bar{X}$)	Principal Firms: Std.Dev (σ)	Industry Totals (T)	Variations About the Trend $\left(\frac{\bar{X} - T}{(\sigma)}\right)$
Aerospace	12				
Sales		13.8	4.8	6.1 (7.7)[a]	1.6 (1.3)[a]
Employment		9.4	2.9	6.3	1.1
Chemical	7				
Sales		5.9	3.2	3.6	0.7
Employment		5.1	5.2	1.4	0.7
Electrical Equipment	5				
Sales		6.5	2.4	3.1	1.4
Employment		5.7	1.7	4.0	1.0
Steel	7				
Sales		8.4	2.1	7.0	0.7
Employment		5.8	1.9	4.4	0.7
Aluminum	3				
Sales		6.1	1.7	4.4	1.0
Employment		5.7	1.8	n.a.	n.a.

Notes:

n.a. Indicates not available.

[a]Industry variability is that of the aircraft industry. The sales variability experienced when all weapons and space development and procurement expenditures are included is shown in parentheses.

Source:

Appendix A.

It can be argued that variability *per se* is not necessarily undesirable. It may be that the nature of the task makes high variability a natural result and to eliminate it would be very expensive. We return to this issue in Section IV. It is also possible that variability has a therapeutic effect. By confronting the firm with occasional adversity, cost reductions of a fundamental sort might be secured that would not be obtained otherwise.* In the opinion of the author, however, the argument for therapeutic effects is less than convincing in the defense industries where the government regards evidence of excess capacity as favorable to contract awards. Indeed, if adversity is known to be transitory, the incentive to achieve cost corrections is attenuated and the alleged therapeutic effects vanish. Thus, unless task characteristics naturally impose a high level of variability on the firms in the defense industries, so that large systems are necessarily contracted for as units and go through a regular cycle of initiation, rapid growth, peaking, and tailing off, the variability observed in the aerospace industry would appear to be without justification. In short, it imposes obvious costs and -- task requirements aside -- no obvious benefits. This study will therefore proceed as if both efficiency and stability performance in the defense industries leave something to be desired; the question of task requirements is deferred to Section IV.

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*For evidence in favor of this proposition see O. E. Williamson, *The Economics of Discretionary Behavior*, Englewood Cliffs, N.J., 1964, Chapter 6.

II. COST PLUS FIXED FEE CONTRACTS

There appear to be three criteria by which defense contracts are awarded: the capability of the contractor, his reputation, and the merits of the proposal. The contractor's capability is measured in terms of his stock of plant and skills. Since previous investment in either equipment or personnel adds to this stock, the prospects that the firm will be awarded contracts in the future can be improved by expenditures of both kinds. Such investments will be further reinforced if evidence of the firm's unused capacity, relative to that of its rivals, weighs favorably in the evaluation of capability.

Capability, which is a measure of the contractor's existing capacity to undertake and complete a task, should be distinguished from his reputation. The latter is concerned with the efficiency and quality of performance of work that the contractor has done previously. Previous cost experience is, of course, an element of reputation, but for a given level of quality, costs in defense work can vary over a wide range and still be considered admissible. Generally, technical uncertainties are too great and change orders too numerous to assign cost performance evaluations with confidence. Thus, as we shall argue, and as has been observed elsewhere, the nature of defense work frequently makes it difficult to assign a penalty for cost overruns.*

The technical merits of the proposal (together with the skill with which it is presented) constitute the third criterion. In contract awards of the magnitude typically involved in the defense industries, much talent and expense go into the preparation and packaging of the proposal.

If, as we have suggested, cost performance is difficult to measure, and if, in addition, this criterion often conflicts with other criteria, cost performance considerations will tend to be displaced in favor of other considerations. This is what we believe has occurred, and we will try here to discover the incentives and related conditions that

*Scherer, op. cit., Chapter 4, especially p. 101.

have combined to produce this result. We begin by examining the cost plus fixed fee (CPFF) contract, which (although no longer much used in procuring major systems) has been used often in the past, and which serves as a convenient starting point for our analysis.

The overriding justification of CPFF contracts is that of cost uncertainty. R&D clearly entails substantial uncertainty, and early production runs frequently involve product modifications and technique developments that render cost estimation on these items difficult. These conditions are well known and hardly require elaboration here. What we want to call attention to is that it is not merely cost uncertainty, but uncertainty together with large size, that is responsible for the large financial risk associated with defense contracts. Were it possible to pool risks by distributing the firm's efforts across a variety of projects instead of on only a few, then, by the standard theorems on portfolio selection,* the risk of ruin could be reduced significantly. If, however, systems are contracted for as a unit rather than by separable components, the financial risk remains high and contractors have been reluctant to bear it.

It would be possible, of course, through the prospect of large profits, to overcome the firm's aversion to heavy financial risk. But the Services are particularly sensitive to public and Congressional criticism when contractors earn large profits,** and thus the Services have been unwilling to offset the variance and risk inherent in large programs by increasing the expected return. A natural way out of the dilemma is to adopt a CPFF contract. The risk of ruin is removed and the contractor is protected. At the same time, moderate profits -- but no more than moderate profits -- are assured, and the Services are also protected.

Assume for the moment that decomposition of the task into many sub-tasks is technically feasible at zero or low cost. (This assumption is discussed below in Section IV.) Assume also that whenever

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*For example, Donald Farrar, <u>The Investment Decision Under Uncertainty</u>, Englewood Cliffs, N.J., 1962, pp. 17-18.

**Scherer, <u>op. cit.</u>, p. 225.

uncertainty can be avoided at zero cost it will be. If both these assumptions are correct, why has task decomposition failed to occur? The answer suggested here is that the conventional assumption that uncertainty is undesirable fails to hold for defense contracting. It will be argued that the Services and the contractors both accept task uncertainty because of the beneficial consequences that each associates with it.*

Uncertainty is valued by both parties because it permits them to justify the CPFF contract arrangement. But of course it is not the contractual arrangement *per se*, but the related consequences that obtain jointly from a CPFF contract and the existence of uncertainty that are valued. For the contractor, these benefits are associated with the fact that the existence of uncertainty makes it difficult to assess efficiency reputation effects with any degree of confidence, and the cost reimbursable features of the CPFF contract make it attractive to increase current expenditures on items that yield satisfaction That is, not only will current expenditures be reimbursed, but the inability to assess cost effectiveness means that future contract evaluations will be substantially unaffected by any overrun costs that are incurred. Hence the contractor has the incentive to expand those expenditures that improve his future capability, for example, investment in plant and personnel. There is likewise an incentive to relax any burdensome on-the-job pressures designed to achieve operating cost economies, for, under a CPFF contract, in terms of forgone profits, the cost of relaxing pressure is effectively zero. The argument is simply an application of the principle that when the relative price of realizing an advantage is reduced, the activity involved will be expanded. Similarly, when the penalty for relaxing an effort which

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*Our emphasis throughout is on task uncertainty. It should be recognized, however, that there are other types of uncertainties that are associated with defense work. Among these is "program" uncertainty, which arises over the possibility that a program will be canceled. Unlike task uncertainty, program uncertainty has, from the standpoint of the contractor, no beneficial consequences associated with it and hence contractors display the usual aversion to uncertainty of this kind.

yields individual disutility is reduced, less effort of this sort will be forthcoming. We merely note that the existence of uncertainty leads to both types of results by permitting CPFF contracts to be justified while simultaneously making cost performance reputation effects difficult to assess, at least over a wide range. For this reason, uncertainty is valued by the contractor.

The difficulty of assessing cost performance reputation effects, and therefore the difficulty of assigning penalties, deserves further discussion. These difficulties arise from the variety of factors that, in principle, can contribute to large cost overruns on contracts that involve uncertainty and extend over a period of years. Typically these factors have two characteristics: their existence is easy to establish qualitatively but difficult to estimate quantitatively. Price and wage changes are among the factors making for uncertainty, as also are changes in technology that may give rise to revised system requirements of indeterminate cost. But even if neither of these types of changes occurred, the very existence of substantial cost uncertainties at the inception of the task may be invoked as the reason for the overrun. As long as cost overruns, for whatever reason, can be made "defensible," penalties for previous cost excesses will be difficult to assign.

As mentioned earlier, cost-reimbursement-type contracts in which overrun penalties are weak or lacking will produce two effects: there are incentives to expand those expenditures that improve the contractor's future capability and to relax any burdensome on-the-job pressures designed to achieve operating cost economies. Of these effects, the one that we wish to emphasize is the tendency to expand "investment" type expenses and thereby improve capabilities. We therefore investigate these effects in some detail in Appendix B. Very briefly, we argue that wherever the prospects of future contract awards are enhanced by currently expanding technical staff and by acquiring technical experience, present staff expenditures will be increased accordingly. More precisely, a firm will employ additional personnel up to the point at which the discounted value of <u>future</u> benefits is equal

to its current marginal cost. Under CPFF contracts current marginal cost is zero. The government reimburses the whole of these expenses and the contractor bears none of the cost. Although this is actually an overstatement, for cost constraints are sometimes invoked and some types of expenses may be disallowed, staff may be expanded enormously, with a tendency to favor in-house R&D rather than to contract the work out. In support of this, Scherer observes that there is a tendency to hoard

> engineers, technicians, skilled production workers, and administrative personnel not required on current contracts but useful for winning and executing future contracts.... Performing work "in house" which could be done more efficiently by specialist vendors is another means...of building up new capabilities for future business. Engaging in technical tasks and buying equipment essentially unrelated to an ongoing development effort also enhances an organization's ability to compete in new fields for profitable future contracts.*

Thus far we have focused on the reasons why task uncertainty is valued by defense contractors. We turn now to consider the reasons why it may also be valued by the Services.

The principal reason why task uncertainty is likely to be valued by the Services is the ready justification or defensibility that it provides. It permits the Services to justify the CPFF arrangement and thereby guarantees that no windfall profits will be realized for which the Services might be criticized. Assuming that they are able to exercise control over conspicuous costs (such as salaries, advertising, travel, entertainment, and so forth), and the evidence suggests that these are in fact closely scrutinized,** the Services (and the contracting officers) are unlikely to be found vulnerable.

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*Scherer, op. cit., p. 183.

**Ibid., p. 205.

At the same time, the Services may feel secure in approving other types of costs (both operating and "investment") which, given task uncertainty, require expertise to evaluate and hence are less subject to Congressional review. Indeed, the Services may be sympathetic to the notion that each contractor should develop something like a complete capability. In some sense this may appear to enhance the defense posture of the country, and, as Enthoven and Rowen have observed, "the Services are concerned primarily with the defense of the United States and not with saving the taxpayers' money."*

An additional if indirect reason why the Services may value (or at least accept) uncertainty, arises from the positive relationship between program size and uncertainty. Large programs tend to be both more uncertain and more "glamorous" (for example, the "man on the moon program"), and because of this glamour it may be easier to obtain public support for them. Moreover, they secure a commitment which, while subject to stretch-out or modification, is infrequently canceled outright.** For these reasons, as well as for the reasons of defensibility and capability, uncertainty has practical advantages for the Services. And with both contracting parties benefiting from it, it is not surprising that efforts have been slow in coming to restructure the task so as to remove uncertainty.

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*Alain Enthoven and Henry Rowen, Defense Planning and Organization, The RAND Corporation, P-1640, July 1959, p. 20.

**Scherer, op. cit., pp. 320-321.

III. INCENTIVE FEE CONTRACTS

As has been indicated, cost uncertainty has net advantages from the point of view of both the contractor and the Service negotiators, and it is plausible to assume that both display some preference for it. Earlier treatments of defense contracting have ignored these advantages and thus, in our view, have provided incomplete explanations for the overrun conditions observed in the weapons acquisition process. Likewise, the failure to distinguish between operating and investment expenditures has frequently obscured the analysis of overrun tendencies. Nevertheless, it has long been recognized that overruns have been excessive and that incentives for cost control have been weak under the CPFF form of contracting. As a remedy for this condition, incentive fee contracts have been employed. These contracts permit the contractor to retain some of the cost savings when an underrun is experienced and require him to bear part of the cost burden when target costs are overrun. Incentive payments are also occasionally tied to technical performance and delivery time, but we will focus on the cost incentive problem.

The Defense Department has recently attempted to shift away from CPFF contracts to those with profit incentive features. Between 1960 and 1964, CPFF contracts as a per cent of total contract awards were reduced from 38 per cent to 12 per cent. The Secretary of Defense reports that "contracts totalling $5.5 billion per year have been shifted from CPFF to fixed price and price incentive formulas.... At a minimum, our analyses indicate that 10¢ is saved for each dollar shifted from CPFF to other forms of contracts."* Among the factors that are said to be responsible for these savings are: (1) more detailed precontract planning; (2) fewer and smaller cost overruns; and (3) improved weapon system performance.**

That there are subtle problems in interpreting the effects of incentive contracts has been widely recognized -- by the Department

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*Memorandum from the Secretary of Defense to the President, Department of Defense Cost Reduction Program - Second Annual Progress Report, July 7, 1964, p. 8.

**Ibid.

of Defense* as well as by numerous economists who have been concerned with the weapons acquisition process. The present analysis reaffirms this view. Indeed, we conclude that it is difficult to establish even the direction of the effect of profit incentives on cost performance, much less the magnitude of the effect.

The principal difficulty in evaluating the effect of incentive contracts on cost performance rests on the negotiation of target costs. If negotiated target costs are identical under both types of contract, and if the technical characteristics of the tasks to be performed are similar, the observation that target costs tend to be overrun using CPFF contracts but underrun when a positive sharing rate is employed clearly suggests that costs are more carefully controlled by the firm under profit-incentive contracts. But the assumption that estimated target costs are unchanged is very much open to question.

It is widely agreed that the contractor is inclined to underestimate full costs when CPFF contracts are used, so as to improve his prospects for winning the contract.** And the Services may, at least tacitly, encourage such underestimation so as to gain budgetary support for the program, while later agreeing to additional fees on overrun costs.*** A substantial identity of interest between the contracting parties exists in these circumstances. When contracts are shifted to incentive fee, however, a penalty for overruns is operative and the attitude of the contractor toward the bargain hardens.

Indeed, whereas an underestimation bias exists when CPFF contracts are in force, an overestimation bias may operate when incentive fee contracts are used, for the greater the differential between negotiated target costs and true expected costs, the larger the potential profit return to the contractor. Thus, if we let π be expected profit, π_T be negotiated target fee,**** C_T be negotiated target cost, C be

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*Department of Defense, Incentive Contracting Guide, 1963, especially pp. 5-23 and 52-54.

**Scherer, op. cit., pp. 27, 131, 157.

***Ibid.

****In practice, negotiated target profit is an increasing function of the sharing rate, α. See Appendix B.

expected cost, and α be the sharing rate, we have $\pi = \pi_T + \alpha(C_T - C)$. Under CPFF contracts, α is zero and hence the difference $(C_T - C)$ is unimportant. When a positive sharing rate is selected, however, the cost difference between negotiated and expected cost necessarily affects profits; and to assume that bargaining behavior is unchanged under the changed circumstances is unwarranted.

It is possible, of course, that any toughening of the attitude on the part of the contractor would be offset by a corresponding toughening in the attitude of the bargaining agent for the government. Indeed, it has been argued that the government, as almost the sole purchaser, has an enormous advantage in its dealings with defense contractors. Moore observes, however, that the government has been either unable or unwilling to realize this monopsonistic bargaining advantage, and suggests that one reason is that it "lacks the skills and resources to make the necessary technical and cost evaluations of contractors' proposals, but instead must rely on information supplied by the firm."* Although it is unquestionably true that the government suffers from an information disadvantage, this is normally the case for the buyer in most buyer-seller relationships. Why should the government be decisively less skillful in its representation for this reason? Indeed, it could be asked, Why should an information disadvantage prove to be a bargaining disadvantage at all? As Schelling has argued (and experimental evidence is not inconsistent with his conclusion), the bargainer with complete information is apt to take a more "reasonable" position than his counterpart whose incomplete information inclines him to bargain "tough."**

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*Frederick T. Moore, Military Procurement and Contracting: An Economic Analysis, The RAND Corporation, RM-2948-PR, June 1962, p. 54.

**T. C. Schelling, "Bargaining, Communication, and Limited War," Journal of Conflict Resolution, Vol. 1, 1957, pp. 19-36. In experimental sessions, differences in bargaining outcomes have been obtained in the direction predicted by Schelling, but not significantly so (see Sidney Siegel and L. E. Fouraker, Bargaining and Group Decision Making, McGraw-Hill, New York, 1960). Although the experimental bargaining situations that they investigated do not obviously generalize to the circumstances that we are concerned with, neither should we want to dismiss out of hand the possibility that incomplete information may have advantages.

Among the conditions frequently cited as evidence of the bargaining disadvantage of the Services are scarcity of eligible contractors, importance of maintaining each source of supply, non-standard character of the product, smallness of lot sizes, and so on, but counterparts could probably be found among firms bargaining between themselves in the private sector -- and the information disadvantage of the customer does not appear to have such overriding consequences. Thus there must be special disadvantages that the government's bargaining agents experience in negotiating contracts with the private sector. Political considerations aside, we would suggest that there are two: asymmetry in rewards, and disparity of status between bargainers.

Consider first the asymmetry of rewards. Our analysis of this effect is based on the following assumptions: (1) an agreement will not be reached unless the maximum price that the buyer is willing to pay is greater than or equal to the minimum price that the seller is willing to accept; (2) other things being equal, the maximum price that a buyer is willing to pay varies inversely, and the minimum price that a seller is willing to accept varies directly with the degree to which price is an objective measure of organizational success; (3) the bargaining posture of a negotiator becomes progressively tougher as the last dollar negotiated has an increasing marginal effect on his personal income stream; (4) within the limits of the feasible bargaining range -- as determined by the attitudes expressed under (2) -- the outcome tends to favor the group with the tougher bargaining stance, as determined by (3). If these assumptions hold, the following propositions will characterize the bargaining outcome: (1) the range of feasible outcomes will be small if the degree of price objectivity is high for both parties, large if the objectivity to each is low, and biased against the party with the lower degree of price objectivity when attitudes differ; (2) within the range of feasible outcomes thus determined, the actual outcome will vary over a small range around the midpoint* if both negotiators are tough, over a large range about the midpoint if both negotiators are soft, and over a small range in favor of the tough negotiator where bargaining postures differ.

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*Choice of the midpoint is arbitrary, but some reference point is needed and the midpoint seems as reasonable as any.

Whereas a condition of symmetry will frequently exist between the negotiators for two firms bargaining over a fixed-price contract, both with respect to the degree of price objectivity and the incentives experienced by the negotiators, it is less clear that an assumption of symmetry is warranted where the bargaining occurs between a firm and the government. Thus, if the contract is CPFF, the marginal loss to the firm for accepting a lower price is only the percentage of allowable profit over cost, which usually runs about 7 per cent. Considering that amendments may permit recovery of the standard rate of return on overruns, the actual valuation may be still lower. Hence, a low bargaining limit by the firm and a weak bargaining posture by its negotiator, whose principal job is to secure the contract, can be expected. If the Services perceive that negotiated costs tend to be self-confirming so that control can be exercised only if target costs are kept low, and further, if it is easier to secure budgetary support when program costs are underestimated, a low ceiling price may be imposed. Under such circumstances, a target cost underestimation bias naturally results.

When profit incentive features are introduced to induce cost control, however, the marginal value to the contractor of the last dollar negotiated is correspondingly increased. Moreover, the firm may simultaneously develop incentives to toughen the bargaining posture by its negotiators. Since the attitudes of the Services and of their negotiators are unlikely to undergo an offsetting change, a systematic increase in negotiated target costs over CPFF levels is predicted. Thus, despite the monopsonistic position of the government, the reward asymmetries that exist when incentive contracts are employed may partly neutralize (or even overcompensate for) this advantage.

Status differentials may also influence the outcome of the negotiations. Thus, we would suggest that where such differentials exist, the low status bargainer tends to display deference toward the high status bargainer and is inclined to adopt a less vigorous bargaining posture. Exceptions are possible of course, but on the average we would expect such attitudes to prevail. In the present circumstances

it would appear that inferior status is generally imputed to the civil servant relative to his counterpart in private industry. Moreover, for the civil servant to take a tough bargaining posture may well produce scorn rather than enhance his professional recognition. The structural advantage (monopsony power) that the government's bargaining agents possess indeed makes it difficult for them to adopt a tough bargaining stance. To do so is to invite the charge of an arbitrary exercise of power that obtains neither from negotiating skills nor superior performance in a prior period, but merely from structural leverage. Tough bargaining here is the mark of a bully rather than a craftsman. As with most professionals, the status of the Service negotiators depends jointly on the evaluations of their employer and of the profession with which they identify. If the Service's rewards for tough bargaining are weak, a tendency to make concessions so as to obtain professional favor seems likely. A more conciliatory bargaining stance may appear to be an appropriate way to secure such favor.*

Thus, we suggest that the importance of imperfect knowledge of the character (and hence cost) of the product is not so much that imperfect knowledge leaves the government's negotiators at a bargaining disadvantage, but that it permits nonobjective considerations to influence bargaining behavior. Where knowledge of product and costs is complete, the appropriate target cost is fully specified. Where this is not true, however, a range of outcomes is possible so that the individual and collective objectives of the parties and the differences

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*These propositions would appear to be testable in laboratory bargaining investigations. In support of this general position we note Scherer's observation that, "Service officials deliberately refrained from pressing for development cost reductions because they wanted to maintain amicable contractor relations, anticipating that a friendly contractor would turn in a quicker and better development job." Op. cit., p. 33. We would suggest that amicable relations are valued by the contracting officers and technical personnel of the Services whether or not they lead to these performance results. Indeed, if there is a correlation between attitude of the Services and performance results, we would predict it is the opposite of that suggested above.

in bargaining posture can affect the negotiations. When CPFF contracts are used, the joint preferences of the parties tend to bias the negotiated target cost downward. However, an upward bias is apt to occur when strong profit incentive features are employed. These propositions are shown graphically in Figure 1.

The upper limit of defensible bargaining postures for the contractor we take as the expected cost E(C) plus an additional amount $k\sigma$, depending on the variance σ. Thus the high variance task (with $\sigma = \sigma_2$) would permit him to offer as a "reasonable" or "defensible" bargaining figure a cost of $E(C) + k\sigma_2$; whereas, with a more well defined task ($\sigma = \sigma_1$) the maximum defensible offer would be a lower target cost of $E(C) + k\sigma_1$. If we assume (1) that the government's bargaining posture (G) is unaffected by variance and (2) that the midpoint between the initial positions -- G, and $E(C) + k\sigma$ -- approximates the negotiated outcome, then a negotiated cost of NC_1 will obtain for the low variance task, but NC_2 will be the result for the high variance task. According to this analysis, with expected costs unchanged, and with the same positive rate of incentive fee (sharing rate) in both cases, increasing the task variance clearly favors an increase in the negotiated contract price. The effect of increasing the sharing rate, we would suggest, would be to move the negotiated price progressively closer to the "defensible" upper limit $E(C) + k\sigma$, for the bargaining stance of the contractor becomes tougher under these circumstances relative to the position of the Service negotiator.

We consider now the effects of increasing the sharing rate on "investment" expenses. Assuming that the firm is operated as a profit maximizer, an increase in negotiated target costs encourages additional expenditures on investment expense while an increase in the sharing rate makes it less attractive to incur current period expenses that yield future period benefits. But an increased sharing rate designed to discourage expenditures on internal technical and administrative expenses may be partly (or even wholly) offset by an increase in the target cost, as discussed above. This is shown graphically in Figure 2 and is proven rigorously in Appendix B.

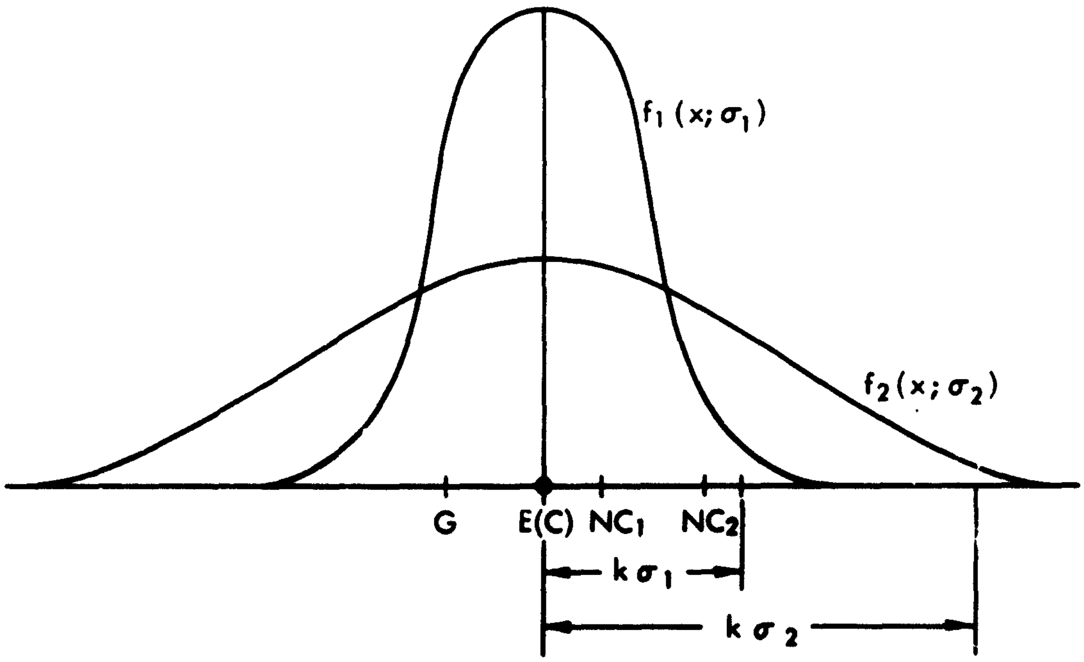

Fig. 1—Negotiated target cost, high cost uncertainty (high task variance) versus low cost uncertainty (low task variance)

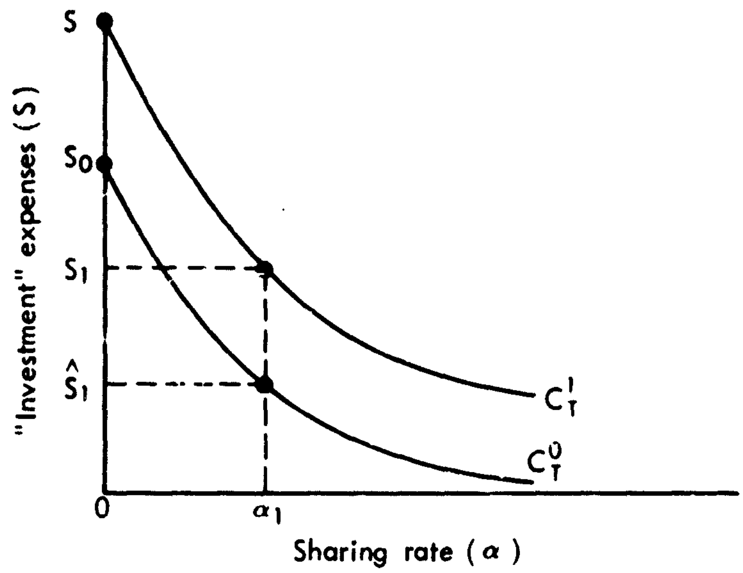

Fig.2—Sharing rate and "investment" expenses

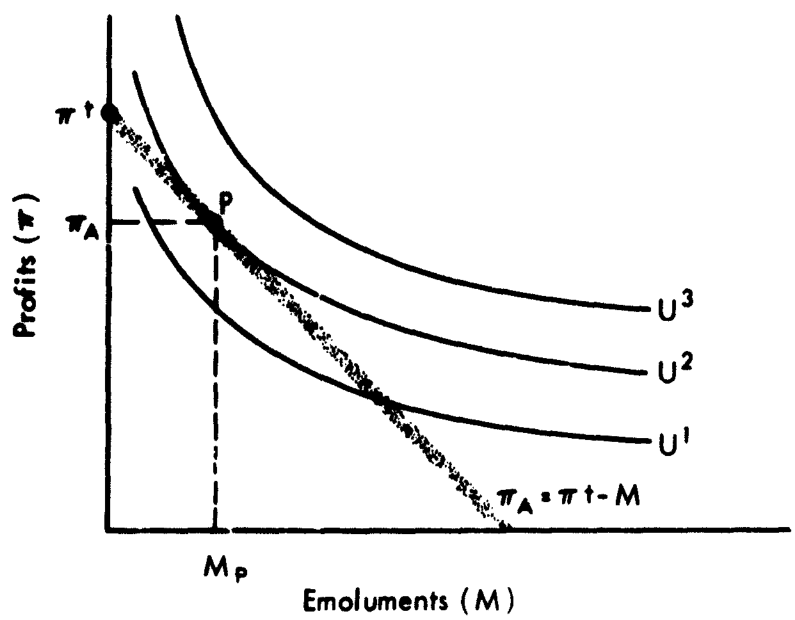

Fig.3—Profits versus emoluments, fixed price contract

We plot the sharing rate (α) along the abscissa and investment expense (S) along the ordinate. For specified values of target cost C_T, let each curve show the locus of optimal S, given the value of α. For $\alpha = 0$ we have a CPFF contract and the target cost C_T^o is negotiated. The optimal value of S in these circumstances is thus given by S_o. If α is increased to α_1, however, a (higher) negotiated target cost $C_T^1 > C_T^o$ obtains. Optimal S is thus given by the value of S that corresponds to α_1 along the locus of C_T^1, namely S_1. Had negotiated target cost remained unchanged, of course, a value of S of $\hat{S}_1$ would have been selected.

If we further generalize the analysis and admit the possibility that defense contractors may be utility maximizers rather than profit maximizers,* we discover further difficulties with incentive contracts. Thus, suppose that the management values emoluments (M) as well as profits (π_A), where emoluments are defined as that portion of management salaries and perquisites that is discretionary. That is, emoluments represent rewards which, if removed, would not cause the managers to seek other employment. They are economic rents and have associated with them zero productivities. They are not a return to entrepreneurial capacity but instead result from the strategic advantage that the management possesses in the distribution of returns to monopoly power.

As we have already indicated, overhead expenditures of this sort tend to be conspicuous and hence are closely monitored. Thus we are inclined to believe that they are quantitatively unimportant. But since emoluments are easy to analyze geometrically, and since all of the qualitative implications that we obtain from the analysis transfer directly to our analysis of operating slack and investment expense, we will perform the analysis in terms of this expense category.

*Scherer considers this possibility but does not fully elaborate it (op. cit., pp. 251-252). I have presented arguments in favor of a utility maximization approach to business behavior elsewhere. See "Managerial Discretion and Business Behavior," American Economic Review, Vol. LIII, December 1963, pp. 1032-1057. A more complete discussion appears in my book, The Economics of Discretionary Behavior, Englewood Cliffs, N.J., 1964.

We represent maximum profits attainable by $\pi^\dagger$, profits realized by π_A, and emoluments by M. Assuming (for the moment) that there are no other expenses for which a positive preference is displayed, we have $\pi_A = \pi^\dagger - M$ and our utility function is given by $U = U(\pi_A, M)$. These relationships are shown graphically in Figure 3 on page 20. Given the willingness to trade off between profit and emoluments indicated by the indifference curves, and given that $\pi^\dagger$ is the maximum profit attainable, the management will realize its utility maximizing position at point P. Thus an amount of profit equal to M_P will be absorbed internally as emoluments.

This analysis implicitly assumes that fixed-price contracts are in force, so that expenditures on emoluments reduce profits on a one-for-one basis. It also assumes that no constraints exist on the amount of emoluments withdrawn. If CPFF or overrun sharing arrangements are in effect, however, the cost of emoluments in terms of profits is correspondingly reduced (to zero for a CPFF contract, to the sharing rate α for an incentive contract). But since emoluments are a conspicuous expenditure class, a constraint on maximum allowable emoluments may be imposed: emoluments in excess of this limit are disallowed, while those less than the limit are reimbursable. Representing the emoluments constraint by $\hat{M}$, we have the cost of emoluments in terms of profits for $M < \hat{M}$ given by α, while the cost when $M > \hat{M}$ is full cost or unity.

If CPFF contracts are in force, maximum profit is target profit ($\pi^\dagger = \pi_T$). The relationships that prevail in these circumstances are shown in Figure 4. For any value of M less than $\hat{M}$, the whole of the expenditure is reimbursed, so that it is only for $M > \hat{M}$ that profit is affected by expenditures on emoluments. We would expect, but it is by no means necessary, that the utility maximizing position occurs at the kink, K, where $M = \hat{M}$. This is the relationship shown in the figure.

If incentive contracts are used, target profit is typically increased. Thus if target profit is an increasing function of α, so

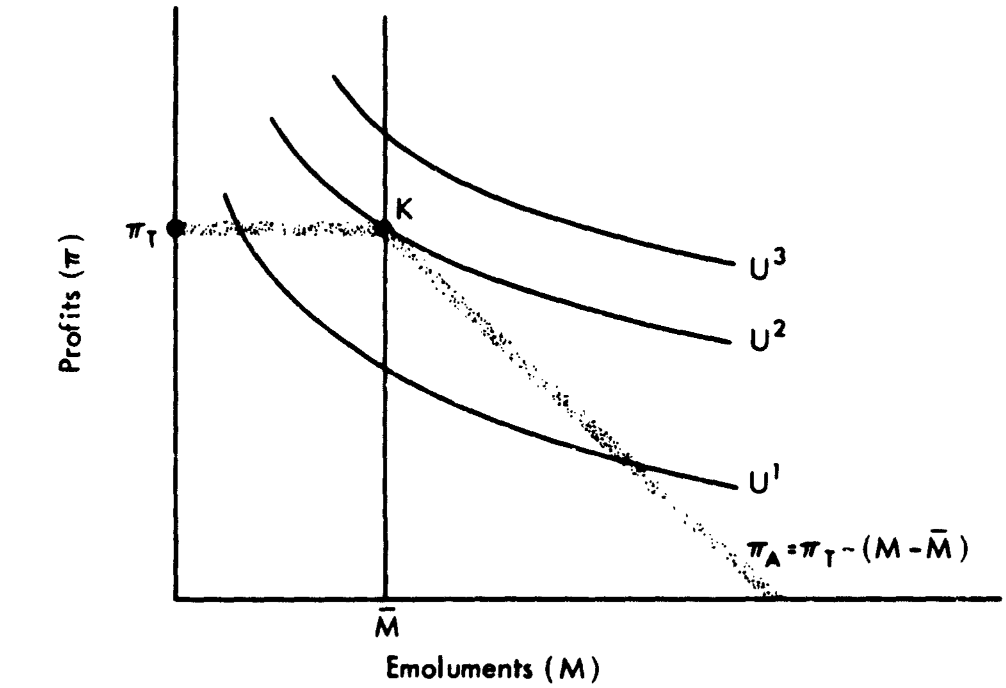

Fig. 4—Profits versus emoluments, cost plus fixed fee contract

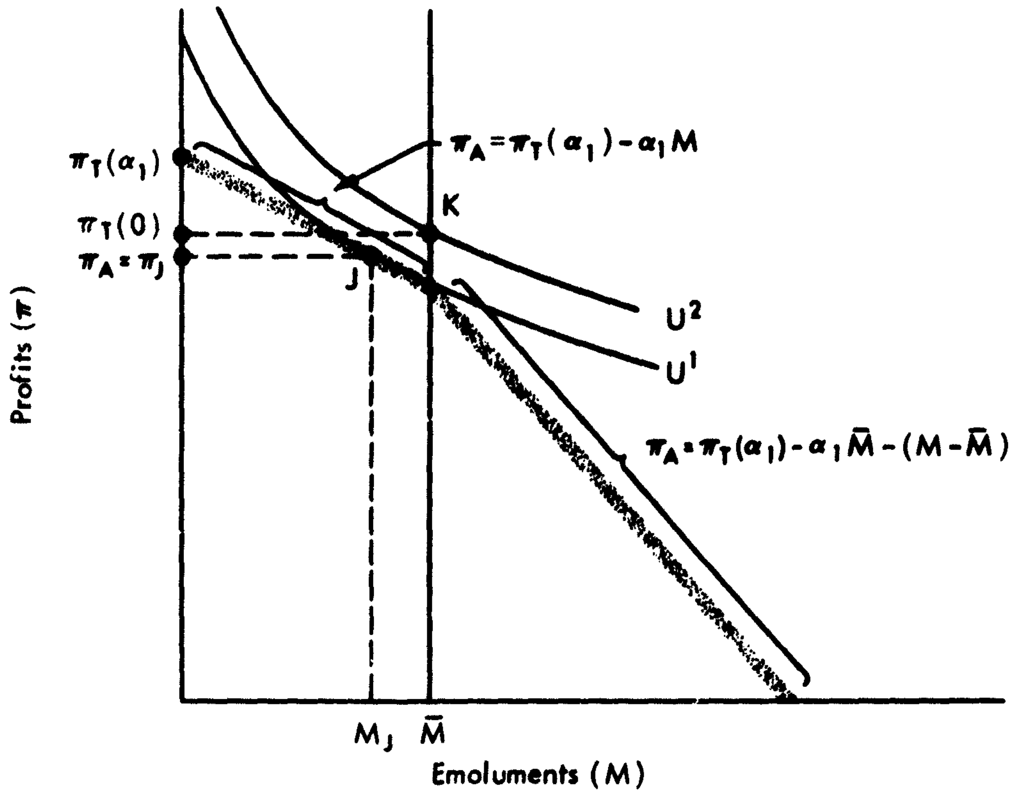

Fig. 5—Profits versus emoluments, incentive contract

that $\pi_T = f(\alpha)$, where $f_\alpha > 0$, we have $\pi_T(\alpha_1) > \pi_T(0)$, where $\alpha_1 > 0$. If target costs are an unbiased estimate of expected (least cost) operating costs, maximum expected profits will be given by $\pi_T(\alpha_1)$ and the relationships that will hold in these circumstances are shown in Figure 5. Here the maximum occurs at J, so that expenditures on emoluments will be reduced below the level $\bar{M}$ by introducing the profit incentive factor α_1 into the contract. As shown, the sum of $\pi_A + M$ at point J is less than $\pi_T(0) + \bar{M}$ at K. Thus the incentive contract has reduced the net cost of the program to the government. This is not a necessary result, however, and depends on how π_T varies with α and on the assumption that target costs are an unbiased estimate of expected actual costs. Indeed, only if the sum of $\pi_A + M$ is less than $\pi_T(0) + \bar{M}$ along the entire line segment $\pi_T(a_1) - \alpha_1 M$ over which the incentive effect is operative can we say unambiguously that the net cost to the government will necessarily be reduced when profit incentives are employed.

If we relax the assumption that target cost is an unbiased estimate of expected actual operating cost and replace it by the perhaps more plausible assumption that a positive sharing rate causes target cost to be biased upward in the bargaining* by an amount Δ, then the maximum expected profit is given by $\pi\dagger = \pi_T(\alpha_1) + \alpha_1\Delta$. The effect of such an increase in negotiated target costs is to displace the feasibility locus of attainable combinations of π_A and M, as shown in Figure 5, vertically upward. The new relationship is shown in Figure 6. The optimum here occurs at J', where $M_{J'} > M_J$ and $\pi_{J'} > \pi_J$.**/ Under the

*We have argued earlier that target cost C_T is less than expected cost E(C), when $\alpha = 0$. Here we argue that a positive sharing rate tends to increase the value of C_T. More formally, if we let C_T^o be the value of C_T when $\alpha = 0$, we have

$$C_T = C_T^o + \Delta\alpha, \qquad \frac{\partial\Delta}{\partial\alpha} > 0, \qquad \Delta\alpha = 0 \text{ when } \alpha = 0.$$

Assuming continuity, there obviously exists a positive value of α for which $C_T^o + \Delta\alpha = E(C)$. That is, a positive sharing rate exists for which the target cost is equal to expected cost.

**This assumes that the marginal rate of substitution of profit for emoluments, given the level of emoluments, increases as profit increases.

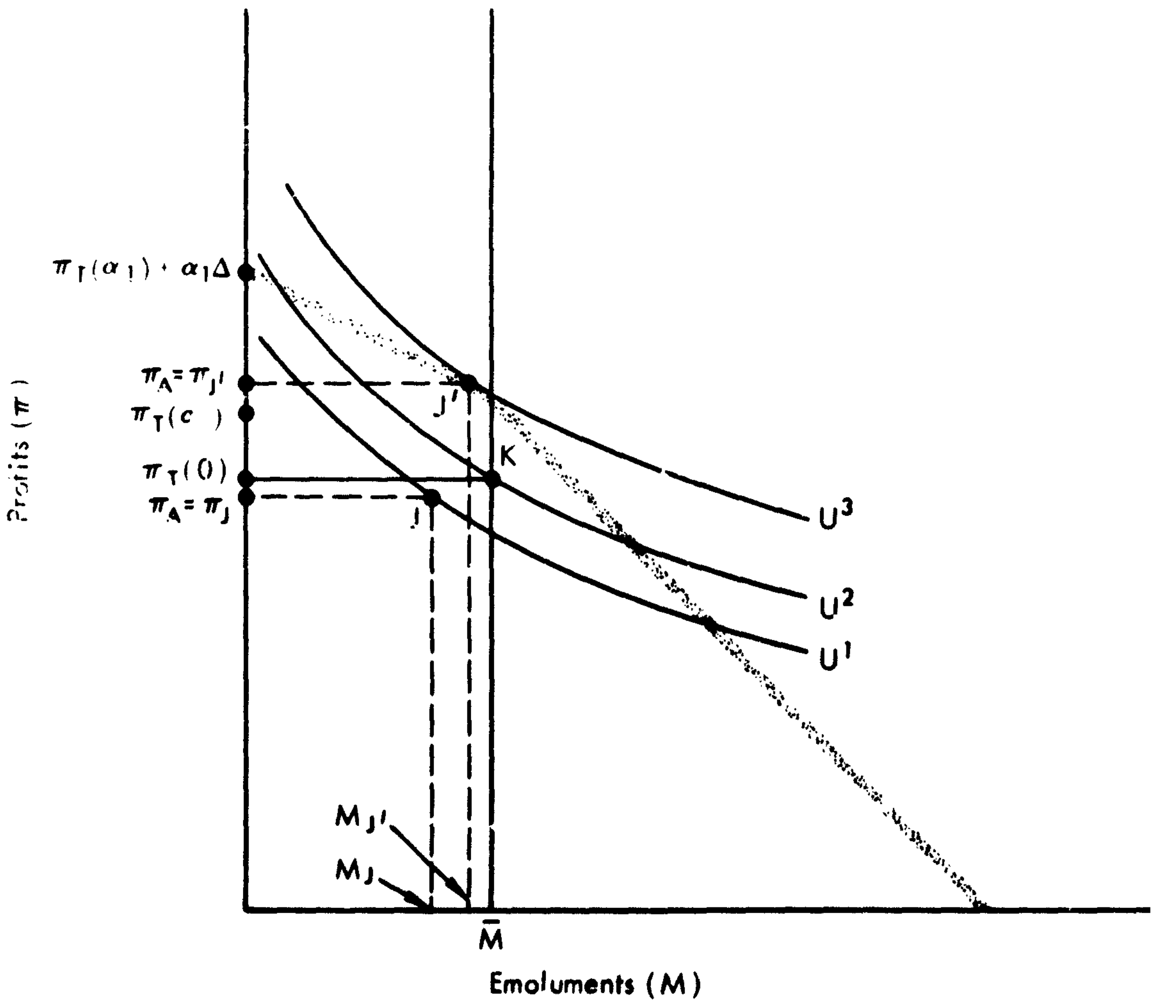

Fig. 6—Profits versus emoluments: Incentive contract with target cost biased upward

conditions shown in the figure, the sum of $\pi_A + M$ at J' exceeds that of $\pi_T(0) + \tilde{M}$. Thus the introduction of the incentive feature here leads to an increase in the net cost of the program to the government -- the reason being that the incentives change relative bargaining postures with the resulting target costs exceeding the expected actual cost. If our preceding analysis of bargaining attitudes when incentive contracts are used is substantially correct, and an increase in negotiated costs normally occurs,* then the advantages of profit incentives are hardly obvious. Indeed, such incentives may lead instead to perverse results!

We might extend our analysis of incentive features to consider the effects of "excessive" profits. If, for example, the contractor has been able to negotiate a very favorable target cost so that there is a large difference Δ between negotiated target cost and expected (least cost) actual cost, and if actual cost experience is favorable so that a large underrun is evident, we could predict further adjustments. Rather than experience a large underrun and thereby subject the Service negotiating team to possible criticism for ineptitude, invite renegotiation proceedings, and possibly damage the firm's reputation when being considered for subsequent contract awards, the contractor is more likely to impose voluntarily a maximum allowable profit constraint ($\bar{\pi}$). If underruns threaten to produce profits that exceed this maximum, the firm may be expected to reduce apparent profits by internal adjustments in its cost structure, rather than move to the unrestricted utility maximizing position. Figure 7 shows these effects.

As shown, the unconstrained optimum occurs at H. However, as $\pi_A > \bar{\pi}$ at H, the firm increases its expenditures on M and shifts to H'. For $\alpha < 1$, $\pi_{H'} + M_{H'} > \pi_H + M_H$ so that the net cost to the government is further increased by this adaptive adjustment.

The analysis can be generalized by introducing into the firm's utility function preferences for operating slack and for additional administrative and technical staff. The assumption that operating slack

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*Scherer reports this is the normal case in the contracts that he examined, op. cit., pp. 226-227.

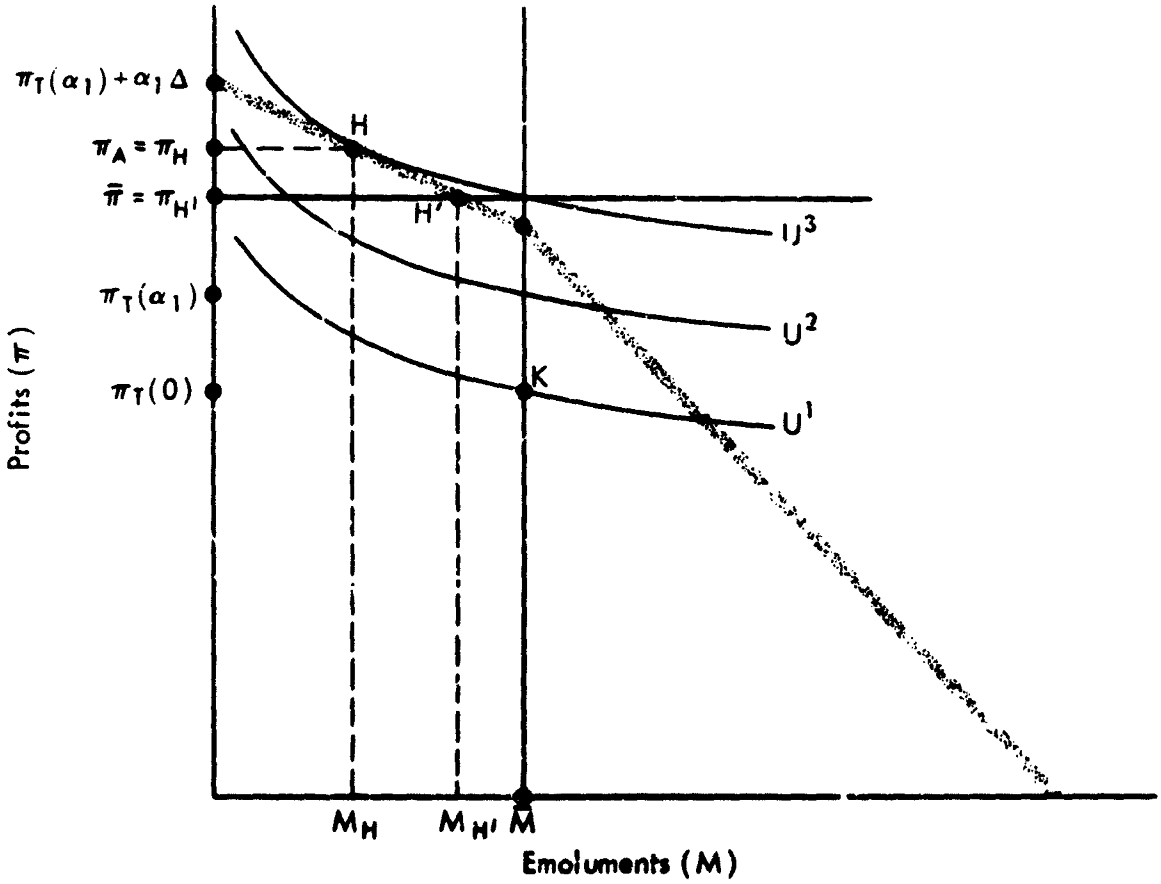

Fig. 7—Profits versus emoluments: Incentive contract with target cost biased upward and profit voluntarily constrained

is valued scarcely requires defense although it tends to be neglected in the usual analysis of business behavior.* That a positive preference for staff exists is due to the variety of ways in which additional staff contributes to the individual and collective objectives of the management. The general reasons for such preferences have been given elsewhere;** the special reasons why these are apparently operative among defense contractors have been noted by Scherer.*** Thus, if we denote operating slack by V_1 and current period staff expense by S_1, and if we shift to a multiperiod context by substituting the discounted value of profit $\hat{\pi}$ for current period profit in our utility function, our augmented function becomes $U = U[M_1, S_1, V_1, \hat{\pi}]$.

The equilibrium properties of this generalized utility function are given in Appendix B. Assuming that the function is Gossen-type (additive in the components) the comparative statics properties can be easily derived. Displacing the equilibrium with respect to the sharing rate α and the target costs C_T leads to the results shown in Table 2. The direction of adjustment of any particular decision variable to a displacement from equilibrium by an increase in either of these parameters is found by referring to columns (2) and (3).

The results reinforce those obtained earlier. As suggested by column (2), manipulating the sharing rate may lead to tighter expense control, but this is by no means inevitable. Unless proper bounds are set on both the increase in the target profit that is allowed when the sharing rate is raised, and the target cost that is negotiated, the net cost to the government may well be increased by introducing profit incentives. As suggested by column (3), much more dependable results

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*"Operating slack" may be looked at as on-the-job leisure. Viewed in this way, the preference can probably be accepted without further explanation. It corresponds (roughly) to a preference for the "easy life" and can be expected to increase as cost performance pressures are relaxed.

**Oliver E. Williamson, The Economics of Discretionary Behavior, Englewood Cliffs, N. J., 1964, Ch. 3.

***Scherer, op. cit., pp. 240-242.

Table 2

COMPARATIVE STATICS RESPONSES FOR
THE GENERALIZED UTILITY FUNCTION[a]

Decision Variable		Shift Parameter: Sharing Rate α	Shift Parameter: Target Cost C_T
(1)		(2)	(3)
Emoluments	(M_1^o)	?	+
Staff	(S_1^o)	?	+?
Operating Slack	(V_1^o)	?	+

Notes:

? Indicates uncertain change in decision variable expense (as result of increase in sharing rate).

\+ Indicates increase in decision variable expense (as result of increase in target cost).

[a]See p. 28 and Appendix B.

could be secured by taking measures that enhance the fidelity of the negotiations that determine target cost.*

In addition to the expense effects identified above, there are other reasons for being less than sanguine about the advantages claimed for incentive contracts. For one thing, if bargaining becomes "tougher," involving more people and more protracted negotiations, additional resources are being used that should be taken into account on the cost side.** Similarly, the administrative cost of making contract amendments tends to rise when incentive contracts are used.*** Finally, a problem of allocating common costs arises when the contractor is working on several programs with different sharing rates. The contractor can improve his net profits by assigning these common costs to CPFF or low sharing rate contracts, thereby further distorting an evaluation of profit incentives on expense control. Thus coordination of expense control efforts between contracts as well as within contracts may be required to arrest any such tendency.

The net impression is that, in the circumstances in which incentive contracts have been used, it is unclear whether such contractual arrangements are likely to induce better expense control by the firm.**** Under ideal conditions, of course, they may -- but as the analysis in Section IV indicates, there are other possibilities that may possess greater merit. And if scepticism over incentive features is warranted when the analysis focuses on simple profit sharing incentives alone, it is apt to apply all the more when multiple incentive fee arrangements are proposed.

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*This analysis thus supports the observation that "the real opportunity for savings and strengthening of incentives may lie in improving the procedure for the setting of cost targets." Charles J. Hitch and Roland N. McKean, The Economics of Defense in the Nuclear Age, The RAND Corporation, R-346, March 1960, p. 232.

**Scherer notes that, compared with cost plus fixed fee contracts, incentive contracts require more extensive negotiation. Op. cit., p. 349.

***Ibid., p. 238.

****R. E. Johnson and G. R. Hall, in a forthcoming RAND study on Public Policy Toward Subcontracting, argue that there may be other advantages associated with the incentive form of contracting, including more careful task definition and the enlargement of the field of competition.

IV. A POSSIBLE ALTERNATIVE APPROACH

The foregoing analysis emphasized the importance of adaptive responses to alternative contractual arrangements by the Services and their defense contractors. It is argued that if such adaptive responses are not taken into account, the relative merits of the different contract types cannot be properly evaluated.

We believe that the principal reasons why special problems arise in defense contracting are the asymmetry of incentives on the two sides, and the unusual degree of discretion arising out of relatively large task uncertainties. Whereas under normal contracting conditions private parties seek to avoid uncertainty, in defense procurement the Services and their contractors may well attach a positive value to task uncertainty because it can be turned to mutual advantage. The adaptive arrangement first devised was the cost plus fixed fee contract. The existence of task uncertainty makes the CPFF contract defensible <u>as a form of contracting</u>. The government appears to be the party best suited to bear the risk, and this form of contract effects this result. If this were the only consequence, the CPFF contract would appear to be an appropriate means by which to handle the uncertainty, but this is not the only consequence. Given such a contract, the Services are assured that profits will not be excessive, and hence much possible public criticism is forestalled. In addition, the CPFF contract encourages contractors to submit artificially low bids (as subsequent overrun costs are borne entirely by the government), and this cost underestimation may make it easier for the Services to "sell" a program. Both the Services and their contractors can also use uncertainty as a defense when the overrun costs are actually experienced.

The most serious criticism of the CPFF contract is the lack of incentives to exercise rigorous cost controls. Indeed, given that a firm's "capability" can be enhanced by making current period expenditures (the private marginal cost of which is zero), the firm has an incentive to expand rather than shrink its expenditures on technical

and administrative staff and on in-house research programs generally. This holds true even if we assume that the firm's utility function is restricted to profits and profits alone. If indeed its utility function includes other than profit components, such as staff, operating slack, and emoluments, additional expenditures of these types will occur (see Appendix B). The Services may be sympathetic to the idea of developing additional technical capability and therefore spending on staff may be actively encouraged. Thus, the CPFF contract not only assigns the burden of risk to the government, as intended, but leads to a variety of adaptive responses that operate to the individual and collective advantage of both contracting parties, but which from the standpoint of society as a whole are dysfunctional responses (for which the marginal social costs exceed the marginal social benefits).

The implicit sharing rate under the CPFF contract is zero. Because this arrangement has properties found to be desirable to both parties, we would predict that both parties would attempt to preserve these advantages by favoring low sharing rates _given_ that they must adopt a type of incentive contract. This appears to be supported by the facts.* In addition, we would predict that contractors would respond by changing their posture at the bargaining table. The combination of reward asymmetry and status inferiority _together with cost uncertainty_, we have argued, operates to the disadvantage of the Services and leads to an upward bias in target costs over those negotiated under CPFF contracts. In addition, higher target profit is allowed when positive sharing rates are used, so it is entirely possible that the net cost to the government increases rather than decreases under these circumstances.

If our analysis of adaptive response to contractual conditions is substantially correct, it suggests that simple manipulation of the

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*In 130 contracts examined by Moore (_op. cit._, p. 46), the highest contractor sharing proportion was 30 per cent, and only five contracts had this high a sharing rate. The median sharing rate was 20 per cent.

sharing rate is a generally unsatisfactory way of inducing good performance. However, as our comparative statics analysis indicates (see Figures 2, 6, and 7, and Table 2), if tighter target costs can be negotiated the prospect of gaining better expense control is improved. But such advice is idle unless it is accompanied by a set of operational procedures by which such a change can be secured.

The fundamental reason for the difficulties surrounding the negotiation and administration of defense contracts, we have emphasized, is the technical and cost uncertainty associated with the task. If this uncertainty could be reduced, there would be less opportunity to bias the negotiations or to incur needless expense. Consider the effect on negotiations first.

We suggest that the opportunity to bias the negotiated target cost upward is a function of the range of possible cost outcomes as perceived ex ante. Where knowledge of costs is imperfect and the cost variance is large, a wide range of possible costs exist (see Figure 1). Bargaining posture is of critical importance in these circumstances, and where asymmetry exists, a systematic bias in favor of the tough bargainer will result. If incentive contracts are used, the contractor is apt to adopt the tougher stance. Where knowledge is more complete, however, objective considerations override bargaining attitudes,* and the opportunity to bias the outcome is correspondingly reduced. Under these conditions the contractor cannot easily support cost estimates that exceed actual costs, and the Service negotiators can more easily detect and refuse biased figures.

In addition, with cost uncertainties substantially removed, contract performance comes in for closer scrutiny. Discretionary expense items are more difficult to justify. Moreover, such overruns as may occur under these circumstances can be more easily attributed to contractor performance rather than chance, so that cost performance reputation effects can be made binding and future contract awards can be made more contingent on present period performance. Thus there

*Siegel and Fouraker found in experimental sessions that increased knowledge reduced the range of bargaining (op. cit., p. 87).

is an inducement to exercise cost control, not merely for its effect on current profits, but also for the promise of future awards. Whereas incentive practices currently in use may fail to discourage expenditures that enhance the contractor's future capability and current satisfaction, the introduction into the contractual relationship of a binding reputation effect would help to attenuate expenditures of these types.

Among the costs that can be reduced if advance knowledge of the task is more complete are the contract administration costs. Where substantial task uncertainty exists, the contracting officers responsible for the direction of the task are apt to demand detailed progress reports and close, continuing inspection so as to be able to defend the program and their own actions in relation to it. The demands for "full information" that arise out of this felt need for defensibility can be reduced, however, if uncertainty is reduced prior to the time of the negotiations. If this can be done, the perceived threat of being assigned responsibility for failure is alleviated, and the incentives to devise elaborate control devices are correspondingly weakened.*

The manifold advantages of reducing task uncertainty should thus be clear. The means by which this result can be obtained have yet to be specified. What follows is an attempt, admittedly tentative and preliminary, to suggest how this might be done.

Our principal proposal is to use task partitioning as a device for reducing the conditional uncertainty that exists between system components. Thus suppose that a particular future period capability is proposed and that general feasibility estimates indicate that the expected costs of the capability justify going ahead. Assume also that the system can be partitioned into components that can be ordered sequentially in such a way that the costs of "later period" components are conditional on preliminary work on "early period" components.

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*Existing control systems would not automatically disappear. Their elimination would require a determined effort from above. But assuming that task uncertainty can be substantially reduced, the incentives to resort to these control devices will be weakened, and thus the controls, once eliminated, are unlikely to recur.

Assume finally that the variance associated with the overall cost of the system is both large and partly attributable to the conditional relations that exist between successive components. Thus, whether component C_3 has expected costs of K_3 or βK_3 (where, say, $1/2 < \beta < 2$) dollars depends on the results of preliminary work on component C_2. If the contract provided for a single, unified, fully integrated system at the outset, the uncertainty associated with component C_3 due to the conditional relation that it bears to C_2 would be unavoidably built into the contract. If, however, actual work on C_3 will be deferred in any case, and if the degree of uncertainty associated with C_3 will be reduced by the information and experience acquired in C_1 and C_2, there is no necessity to include C_3 in the initial contract. Rather, once it has been established that the expected costs of the total system are acceptable, the initial contract can be limited to "early period" components. As work on these progresses (but not necessarily to completion) and the relations between these and successive components becomes clear, "later period" components, the specifications for which are now better defined, can be sequentially added (or, in the event that work on early stages of the system reveals exorbitant costs, the program may be canceled). Since (by assumption) uncertainty is progressively removed by proceeding in this stepwise fashion, the opportunities to bias cost estimates in the contract negotiation stage and to escape cost performance reputation effects at the evaluation stage are correspondingly reduced. Hence, both more accurate target costing and tighter expense control could be expected.

Ideally, partitioning would proceed to the point where the expected marginal benefits are just offset by the expected marginal costs. Attempting to achieve any such optimality obviously requires that we consider whether or to what extent additional advantages inhere in this approach and what the costs might be.

The merits of the proposal for partitioning the task in an attempt to reduce uncertainty are not confined to the fact that this improves the quality of the target cost estimates with the attendant benefits

indicated above. This proposal complements two other recent proposals for restructuring the approach to R&D: the Klein-Meckling-Nelson* proposal for parallel R&D, and the Enthoven-Rowen** proposal concerning the mix of capabilities required.

Klein and Meckling argue that the comprehensive, system-planning approach to development decisions is inappropriate for many or even most developments. They hold that the problem is not "one of choosing among specific end-product alternatives, but rather a problem of <u>choosing a course of action initially consistent with a wide range of such alternatives</u>; and of narrowing the choice as development proceeds."*** They therefore approach the R&D problem as a sequential decision problem in which parallel R&D is conducted on components rather than systems. The potential cost savings inherent in this approach (at least under certain ideal circumstances) have been analyzed by Nelson, and the project histories reviewed by Marschak suggest that such savings could be realized.****

The argument of Enthoven and Rowen is that a broad spectrum of capabilities is needed and that "research and development policy should aim at preventing the creation of a few, large-scale programs, which large and powerful interests will want to preserve, before the major uncertainties have been resolved." Instead, we should encourage "competition, duplication, and overlap...[as] the price we pay for the reduction of uncertainty."***** Unpublished RAND studies by McKean and Schlesinger support this view and argue that decentralization of

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*Burton Klein and William Meckling, <u>Application of Operations Research to Development Decisions</u>, The RAND Corporation, P-1054, March 1958, and R. R. Nelson, "Uncertainty, Learning, and the Economics of Parallel Research and Development Efforts," <u>Review of Economics and Statistics</u>, November 1961, No. 43, pp. 351-364.

**Enthoven and Rowen, <u>op. cit</u>.

***Klein and Meckling, <u>op. cit</u>., p. 352; emphasis added.

****Nelson, <u>op. cit</u>., and T. A. Marschak, <u>The Role of Project Histories in the Study of R&D</u>, The RAND Corporation, P-2850; January 1964.

*****Enthoven and Rowen, <u>op. cit</u>., pp. 369 and 372.

R&D decisionmaking will help secure greater diversity. The task decomposition that we propose would appear to make this objective easier to achieve, at least in the earlier stages of development.

It is perhaps also relevant to observe that, although the data are incomplete and the details are not entirely clear, task partitioning has been practiced successfully in French aircraft development. To the extent that crude comparisons are meaningful, the cost of these programs relative to American experience appears to be substantially lower and development time has also been reduced. No doubt there are a number of factors that are responsible for these differences. If our arguments for partitioning are correct, however, task partitioning would at least appear to be a contributing factor and may explain a significant fraction of these performance differences.

Such a partitioning can lead to further benefits if, as a result of the reduction in the average size of the contract, an increased number of firms can qualify for consideration when contracts are awarded. Where entire systems are contracted for as a package, only a few large defense contractors can fulfill prime contractor qualifications. Thus, competition for these awards, limited to a handful, may be less effective than it might otherwise be, and confidence in the fidelity of the negotiations will be impaired. By opening up the bidding to a larger number of firms, task partitioning may well lead to a more objective determination of costs even if uncertainty remains substantial.

Finally, task decomposition has the additional advantage that it may help to avoid "boom and bust" in the sales and employment of defense contractors. The cyclical adjustment in the volume of operations associated with a large system as it goes through the phases of initiation, rapid growth, peaking, and tailing off, would be less marked if the task was partitioned. Instead of a few large programs absorbing the bulk of a firm's (or the industry's) capacity, a number of smaller programs could be in progress simultaneously. Assuming that they were initiated at different times, the result would be a stabilization in employment and sales.

If task partitioning of this sort is feasible and the merits we claim for it are valid, the question arises as to why partitioning has not been done already. Two answers can be supplied. One (and the one we believe has been neglected) is that task uncertainty has been valued for the discretionary opportunities that it affords -- both to the Services and to the contractor. They have therefore been disinclined to restructure the task along the lines suggested. The second answer is that the suggested approach has certain costs, and these may be too great to justify the change.

Some possible disadvantages (costs) of task partitioning may be mentioned. First, task partitioning may lead to serious subsystem-to-subsystem interface problems. Second, the administrative costs of contract proliferation may be substantial. Finally, the partitioning may lead to some losses in economies of scale.

The interface problems may appear to be insuperable. If work on the components proceeds in semi-autonomous fashion, problems of compatibility and of "fitting" at component and subsystem interfaces may well be neglected. Thus any apparent savings realized by splitting the task up may be more than offset by costs of achieving component compatibility later. Moreover, as responsiblity for making the necessary changes might be unclear, administrative costs and delays can be anticipated. In the present author's opinion, however, these expenses may be easily exaggerated. Thus, the usual procedure in a multi-component development program (the contract for which now goes to a single contractor) is for the contractor to follow a course not unlike that described here, only without the benefits that are inherent in advance task partitioning. The component work is likely to be split up and assigned to research groups (some in-house, other to subcontractors) that are responsible for developing a device that meets the principal specifications (among which, of course, are included some crude compatibility requirements). Once this stage has been reached, but not before, additional refinements are made so as to secure more perfect matching between successive "surfaces." However, as all of

the work is done under the cognizance of a prime contractor, the responsibility for performing the interface work is his, and the task goes on to completion without considering these interface costs explicitly. Although they may be disguised, expenses of this sort are nonetheless real. If the need to make interface corrections is recognized and the funds for this purpose are provided, task decomposition would merely make these costs at least partly explicit. Moreover, by recognizing the costs explicitly and providing for the work separately, the problem of responsibility can be reduced. It is by no means certain, therefore, that interface costs would be significantly greater under the proposed task partitioning approach than they are under a prime contractor system approach.

There is a real possibility that contract administration costs would proliferate if tasks were partitioned into components and proposals were split off from development. But the felt need for defensibility tends to be reduced when uncertainty is reduced, so that the demands for Service control are apt to be less under the proposed approach. Furthermore, competition for contract awards is likely to be improved, and individual contract negotiations shortened and made less costly. Although the number of negotiations and the number of contracts will increase substantially if the task partitioning approach is adopted, it is not clear that overall contract administration costs would increase.

Finally, with regard to the argument that scale economies may be sacrificed by making smaller contractors eligible, we would point out that (1) if large firms realize scale economies they will presumably reflect this in the lower bids they submit; (2) the evidence suggests that "in most industries, the productivity of an R&D program of given scale seems to be lower in the largest firms than in somewhat smaller firms,"* so that the alleged loss of scale economies may be imaginary;

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*Edwin Mansfield, "Industrial Research and Development Expenditures," The Journal of Political Economy, August 1964, Vol. 72, p. 338.

(3) our proposal is designed to permit more stable sales and employment so that diseconomies associated with large variation here can be reduced; and (4) the problem of expense control is largely one of incentives and opportunities -- to focus on scale economies narrowly conceived is to miss entirely the dysfunctional aspects of current procedures.

V. CONCLUSIONS

The trend of defense spending is toward R&D rather than procurement. Whereas the sum of spending on research, development, technology, and engineering by the Department of Defense and the National Advisory Committee on Aeronautics in 1953 was 11 per cent of total expenditures for defense development and procurement, this had increased to 37 per cent by 1963.* Moreover, procurement now tends to be in smaller quantities than previously. Hence, if expense control is to be realized at all, it must be realized early. It is no longer sufficient to postpone attention to the problem and resort to breakout and second-sourcing late in the procurement stage to achieve efficiency.

As was pointed out in Section I, there are three ways to approach the problem of contract cost control: (1) to attack it at its root by changing the structure of the task, (2) to induce the desired performance by manipulating incentives, and (3) to adopt direct performance controls. Both (2) and (3) have been tried and, for the reasons given in Sections II and III, have been found inadequate. The principal difficulty is that these approaches fail to shrink significantly the range of discretion. Adaptive responses develop that can easily render the intended control ineffective.** This point, which is basic to our analysis of the effects of incentive contracts, is responsible for the author's skepticism about claims for significant cost advantages for the incentive form of contracting. The analyses from which these claims are derived (see p. 12 ff.) make several implicit "other-things-being-equal" assumptions that are not obviously satisfied. In particular, the proposition that negotiated target costs are unresponsive to the sharing rate is, for the reasons given above, difficult to sustain. Moreover, the multidimensional character of a firm's utility function permits a firm to compensate against controls directed toward any single expense category. In short, the analysis presented in this

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*Scherer, *op. cit.*, p. 57.

**It is for this reason that this author finds Scherer's approach, which leaves structure unchanged but attempts to influence conduct through after-the-fact evaluation by an impartial board, unattractive. *Ibid.*, Ch. 12.

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Memorandum reveals that there is no unambiguous theoretical support for the alleged advantages of incentive contracts, and this applies even if direct performance controls (of the types ordinarily used) are also employed. Rather, the logic of adaptive response suggests that the case for incentive contracts can be established only when explicit attention is given to (and, probably, offsetting action taken against) the indicated adaptive effects.

Assuming that the private contractor form of organizations is to be preserved for defense work, a more direct and possibly more effective way in which to limit the discretionary opportunities that contractors experience is to restructure the problem by partitioning the task into technically separable components. Although this does not preclude using incentive features as well, neither are the advantages of the task partitioning approach conditional on concurrent use of incentive contracts. Among the advantages that partitioning promises are:

o It reduces the amount of uncertainty and hence increases objectivity in contract negotiations, reduces the felt need for defensibility in administering contracts, and permits more reliable evaluations and thus allows cost performance reputation effects to be assigned with confidence. Each of these effects should help to prevent excessive contract costs.

o It creates a contract environment in which the full potential of parallel R&D approaches (as previously advocated by Klein, Meckling, and Nelson) can be exploited.

o It complements R&D strategies which emphasize the need for maintaining options by providing support for work on adaptable components and flexible capabilities (as argued for by Enthoven and Rowen).

o It permits greater competition by increasing the number of eligible contractors.

o It lends itself to sales and employment stabilization.

Against these advantages must be weighed the possible costs associated with (1) possible interface problems, (2) contract proliferation

costs, and (3) sacrifice of scale economies. For the reasons given above, the present author does not regard these as overriding objections. Insofar as they are real problems, they can be minimized by recognizing them in advance.

Admittedly the arguments in favor of task and contract partitioning are controversial, but it is believed that they have sufficient weight to be taken seriously. At the very least, they deserve further research.

Appendix A

SALES AND EMPLOYMENT VARIABILITY

Empirical Results, Variations About Trend, and Corrections for Industry Effect: Average Absolute Residual as a Percentage of Mean Sales and Employment, Principal Firms and Industry Experience for Five Industries, 1954-1963

Industry and Firm	Sales Rank of Firm Among 500 Largest Industrials 1963	Average Absolute Residual as Percentage of Mean: Sales	Employment
Aerospace			
Lockheed	20	7.6	8.5
North American	21	13.7	12.8
Boeing	25	10.3	8.0
General Dynamics	30	17.6	12.6
United Aircraft	33	10.6	3.9
Douglas	75	14.6	9.6
McDonnell	101	19.0	14.5
Hercules	120	8.4	9.0
Grumman	123	11.2	6.0
Republic	155	24.5	8.7
Northrop	162	13.7	9.0
Curtiss Wright	245	14.6	9.8
Total Aerospace Industry		6.1	6.3
All weapons and space development and procurement		7.7	NA
Chemicals			
du Pont	11	3.5	3.5
Union Carbide	27	4.8	3.9
Dow Chemical	52	2.4	1.6
Olin-Mathieson	67	3.2	3.2
FMC	87	9.3	15.8
Koppers	189	10.4	9.0
Stauffer	222	7.8	9.0
Total Chemical Industry		3.6	1.4
Electrical Equipment			
General Electric	4	5.4	6.0
Westinghouse	16	5.6	4.2
Bendix	63	4.5	3.6
ITE Circuit Breaker	424	10.6	6.9
Square D	360	6.2	7.6
Total Electrical Equipment Industry		3.1	4.0

Industry and Firm	Sales Rank of Firm Among 500 Largest Industrials 1963	Average Absolute Residual as Percentage of Mean: Sales	Employment
Steel			
U.S. Steel	6	7.4	4.4
Bethlehem	17	7.4	5.7
Republic	46	9.5	7.8
Inland	64	5.4	2.5
Youngstown Sheet & Tube	84	10.1	6.9
Crucible	218	11.6	7.6
Wheeling	238	7.3	5.6
Total Steel Industry		7.0	4.4
Aluminum			
Alcoa	51	5.1	5.0
Kaiser	129	8.1	7.8
Reynolds	100	5.1	4.1
Total Aluminum Industry		4.4	NA

Sources:

Total aircraft industry and weapon space development and procurement data from Frederick M. Scherer, The Weapons Acquisition Process: Economic Incentives, Boston, Mass., 1964, pp. 57-58.

Firm data on sales and employment from Fortune's 500 Largest Industrials, 1955 through 1964.

Total industry sales and employment data, except aerospace, from Moody's Industrials and Monthly Labor Review, respectively

CORRECTIONS FOR INDUSTRY EFFECT*

If total industry sales fluctuate because of variations in demand for the output of the industry, the variability of sales among the firms in the industry will clearly be affected. Thus, to examine the sales variability experience of firms without correcting for an industry effect is to impute variability to the firms that, in some sense, might be considered unavoidable. Our objective here is to show how, in principle, it is possible to separate out the industry effect on firm variability. Thus, let

S_{ijt} = sales of the i^{th} firm in the j^{th} industry in period t,

$R_{jt} = \sum_i S_{ijt}$ = sales of the j^{th} industry in period t,

$\sigma^2_{S_{ij}}$ = variance about a linear trend of sales in firm i of industry j,

*I am indebted to Roy Radner for helpful comments on this part of the argument.

Our hypothesis of a linear trend is given by:

$$S_{ijt} = \alpha_{ij} + (\beta_{ij})t + \epsilon_{ijt} \tag{1}$$

where α_{ij} and β_{ij} are constants, and ϵ_{ijt} is a random error term decomposible into an industry and firm effect as follows:

$$\epsilon_{ijt} = (\bar{S}_{ij}/\bar{R}_j)\, u_{jt} + v_{ijt} \tag{2}$$

where $\bar{S}_{ij}$ = mean firm sales = $\frac{1}{T}\sum_t S_{ijt}$

$\bar{R}_j$ = mean industry sales = $\frac{1}{T}\sum_t R_{jt}$

and $E(u_{jt}) = E(v_{ijt}) = E(u_{jt}\, v_{ijt}) = 0$.

Letting $(\bar{S}_{ij}/\bar{R}_j) = \gamma_{ij}$, we have

$$\sigma^2_{S_{ij}} = \text{Var}\,(\gamma_{ij}\, u_{jt} + v_{ijt}) = \gamma^2_{ij}\, \sigma^2_j + \sigma^2_{ij} \; . \tag{3}$$

Now, since

$$R_j = \sum_i S_{ijt} = \alpha_j + (\beta_j)t + \sum_i (\bar{S}_{ij}/\bar{R}_j)\, u_{jt} + \sum_i v_{ijt}$$

and since $\sum_i (\bar{S}_{ij}/\bar{R}_j) = 1$, we have

$$R_j = \alpha_j + \beta_j t + u_{jt} + \sum_i v_{ijt} \; , \tag{4}$$

and

$$\sigma^2_{R_j} = \text{Var}\,(u_{jt} + \sum_i v_{ijt}) = \sigma^2_j + \sum_i \sigma^2_{ij} \; . \tag{5}$$

We thus obtain N equations of the form shown in equation 3, and one equation of the form shown in equation 5 to estimate the N variances, σ^2_{ij}, and the industry effect, σ^2_j . In short, we have N + 1 independent equations in N + 1 unknowns and can thus obtain corrected estimates of the amount of sales variability for each firm. Unfortunately, however, the technique indicated requires that we obtain

data on all of the firms in the industry, and hence is impractical for our limited purposes. It should nonetheless prove useful in more detailed studies of variability experience than we have reported here.

Appendix B

ADAPTIVE RESPONSE MODEL

Designating the participation rate (or "sharing" rate) in overruns and underruns as α, the negotiated target profit as π_T, the negotiated target cost as C_T, and actual cost as C_A, actual profit is given by

$$\pi_A = \pi_T + \alpha(C_T - C_A), \tag{1}$$

where all the terms refer to current period results. Our objective is to elaborate the model and extend it to include multiperiod effects.

First we look at the components of current period cost. These are of two types: current period operating costs, C_1, that are essential to contract performance and are mainly of a direct cost nature, and current period "investments" in staff expenditures S_1, that provide the firm with a future period capability and tend to be of an indirect cost nature. Neglecting overrun penalties (reputation effects), the effects of these expenditures are to improve the contractor's capability (real or perceived) and thus improve its eligibility for future period awards.

Target profit can be broken down into target revenue less target cost. Letting ρ be the target rate of return over target cost, and assuming that

$$\rho = \rho(\alpha); \frac{\partial\rho}{\partial\alpha} > 0, \frac{\partial^2\rho}{\partial\alpha^2} < 0 \tag{2}$$

we have target revenue given by

$$R_T = [1 + \rho(\alpha)]C_T. \tag{3}$$

Actual revenue is given by

$$R_A = R_T + (1 - \alpha)(C_A - C_T) \tag{4}$$

so that expected actual current period profits, as given in (1), can be expressed as

$$\pi_A = R_A - C_A = \rho(\alpha)C_T + \alpha(C_T - C_1 - S_1). \qquad (1')$$

The analysis can be shifted into a multiperiod context by letting R_i, C_i, and S_i be revenue, direct cost, and staff expenditure, respectively, in periods $i = 2, 3, \ldots, N$ and by denoting the discount factor in the period by ι_i, where $\iota_i = 1/(1 + r)^{i-1}$ and r is the discount rate. Then our objective becomes:

$$\text{maximize } \pi = \rho(\alpha)C_T + \alpha(C_T - C_1 - S_1) + \sum_{i=2}^{n}(R_i - C_i - S_i)\iota_i. \qquad (5)$$

All that remains before investigating the properties of this model is to specify how future period revenue is affected by current period expenditure. Thus we assume that

$$R_i = \Psi_i(S_{i-1}, S_{i-2}, \ldots S_{i-n}, Z_{i-1}, Z_{i-2}, \ldots Z_{i-n}) \qquad (6)$$

where $\dfrac{\partial\Psi_i}{\partial S_{i-k}} > 0$, $\dfrac{\partial^2\Psi_i}{\partial^2_{i-k}} < 0$ (the "capability" effect);

$\dfrac{\partial\Psi_i}{\partial Z_{i-k}} < 0$, $\dfrac{\partial^2\Psi_i}{\partial Z^2_{i-k}} < 0$ (the "reputation" effect)

where Z_k is the excess of cost over the allowable overrun in period k, and is defined as

$$Z_k = C_k + S_k - (1 + \gamma_k)C_{Tk} \qquad (7)$$

where γ_k is the overrun allowance.*

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*We assume that Ψ_i is separable, so that $\dfrac{\partial^2\Psi_i}{\partial S_k \partial Z_k} = 0$, and that γ is an increasing function of the cost variance, σ.

MAXIMIZATION WITH RESPECT TO "STAFF" EXPENSE

Assuming that the value of α is specified, and treating C_1 as unavoidable costs that must be incurred in order to satisfy the contract, the only decision variable open to the contractor is the amount of expense that has investment-type effects. Differentiating equation (5) with respect to S_1 we obtain:

$$\frac{\partial \pi}{\partial S_1} = -\alpha + \sum_{i=2}^{n} \left(\frac{\partial \Psi_i}{\partial S_1} + \frac{\partial \Psi_i}{\partial Z_1} \cdot \frac{\partial Z_1}{\partial S_1} \right) \iota_i = 0. \tag{8}$$

Taking α to the other side of the equation and recognizing that $\frac{\partial Z_1}{\partial S_1} = 1$, we have:

$$\sum_{i=2}^{n} \left(\frac{\partial \Psi_i}{\partial S_1} + \frac{\partial \Psi_i}{\partial Z_1} \right) \iota_i = \alpha. \tag{9}$$

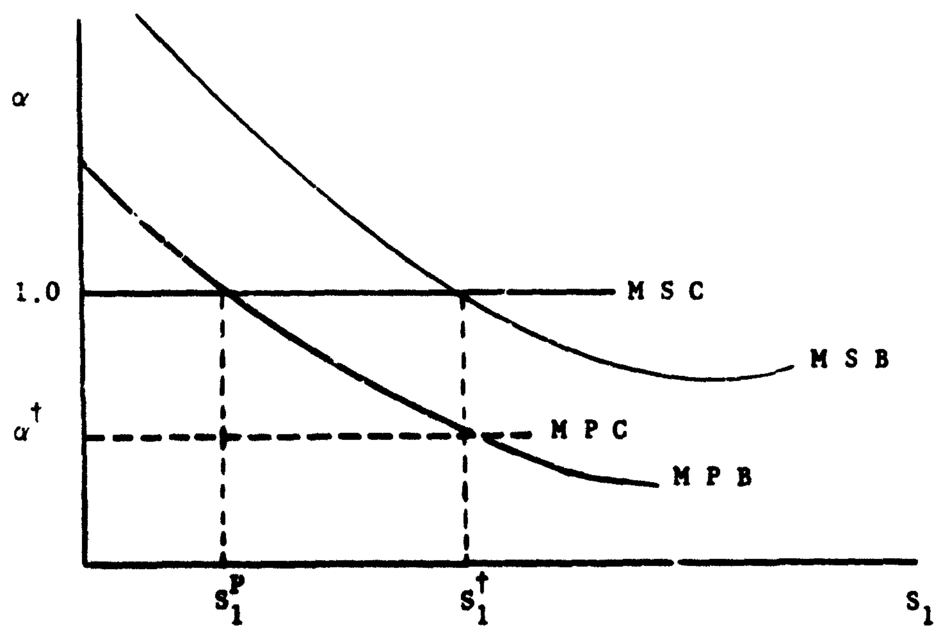
Thus, the discounted value of the marginal future period benefits associated with those current period expenditures that improve the firm's future capability is set equal to the current marginal private costs of making those expenditures, namely the participation rate α.

Taking the <u>total differential</u> of (9), and assuming that second order conditions are satisfied, it can be shown that

$$\left(\frac{dS_1}{d\alpha} \right)^{o} < 0. \tag{10}$$

That is, as the marginal private costs (α) of making expenditures of type S_1 are decreased, the level of S_1 expenditures is increased, as expected. If, therefore, the government is anxious to have current period costs reduced, it will favor a high value of α. Indeed, if it believes that the marginal social and private benefits are the same, while the marginal social costs are 1.0 and the marginal private costs are α, it will favor selecting α equal to 1.0. Should marginal social

benefits exceed marginal private benefits from S_1 expenditures, as may be true when these expenditures have a large R&D component, the government might deliberately manipulate α to induce desirable private performance by selecting that value of α that equates marginal private costs and benefits at the social optimum. This is illustrated in the diagram below.



For α chosen equal to 1.0, the firm will make an expenditure of S_1^P, whereas the social optimum is $S_1^\dagger$. If, however, α is set equal to $\alpha^\dagger$, the firm will voluntarily operate as $S_1^\dagger$, as intended.*

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*The question of the optimal choice of research projects to support by S_1 expenditures is not considered by the above analysis. Thus, we merely know that the firm will select that group of projects that most contribute to its private benefits, and the M P B and M S B curves are drawn for this mix of projects. For the government to induce a different group of projects it must alter the reward structure (the Y_i functions) that the firm perceives, or underwrite specific programs. The latter is more direct and probably more manageable. But if this is true, why not set α = 1.0 and underwrite $S_1^\dagger - S_1^P$ as well as this additional amount of expenditure suggested above? The advantage of not choosing this course is that as long as decentralized decisions are rendered in a socially desirable way, the sources closest to the decisions are frequently best able to make them. Those projects that

An alternative, although somewhat indirect, way of inducing a different choice of S_1 would be to manipulate C_T, since changing the value of C_T gives rise to "reputation" effects. Thus it can be shown that

$$\left(\frac{dS_i}{dC_T}\right)^o = \frac{\sum_{i=2}^{n}\left(\frac{\partial^2 \Psi_i}{\partial Z_1^{\,2}} \frac{\partial Z_1}{\partial S_1} (1 + \gamma_1)\right)}{\sum_{i=2}^{n}\left(\frac{\partial^2 \Psi_i}{\partial S_1^{\,2}} + \frac{\partial^2 \Psi_i}{\partial Z_1^{\,2}} \cdot \frac{\partial^2 Z_1}{\partial S_1^{\,2}}\right) \iota_i} > 0. \qquad (11)$$

A decrease in the negotiated target cost would thus give rise to reduction in staff-type expenditures. This is the case considered in Figure 2 in the text.

THE PARTICIPATION RATE (α) AS A DECISION VARIABLE

If we assume that the firm is free to choose the value of α, that α has no effect on the negotiated target cost, that is, $\frac{\partial C_T}{\partial \alpha} = 0$, but that the target rate of return increases as α increases, so that $\frac{\partial \rho}{\partial \alpha} > 0$,* we have by differentiating equation (5) with respect to α:

---

are neglected by this decentralized decisionmaking are thus left to the centralized authority to make. Thus the heuristic becomes: set α (private costs) at the level that equates marginal social costs with marginal social benefits on decisions privately made; support under a separate program those projects that the private sector neglects by this process.

For a more comprehensive review of the problems of designing an optimal R&D program, see Richard R. Nelson, Technological Advance, Economic Growth, and Public Policy, The RAND Corporation, P-2835, December 1963. Nelson's views on pp. 14-15 are close to those expressed above.

*The assumption that $\partial C_T/\partial\alpha = 0$ seems unreasonable but appears to be implicit in the Department of Defense's evaluation of the cost savings realized from the use of incentive contracts. We employ it here merely for illustrative purposes, but replace it by the assumption that $\partial C_T/\partial\alpha > 0$ later. The assumption that $\partial\rho/\partial\alpha > 0$ is widely made, and is stated explicitly in the 1963 DOD Incentive Contracting Guide, p. 20.

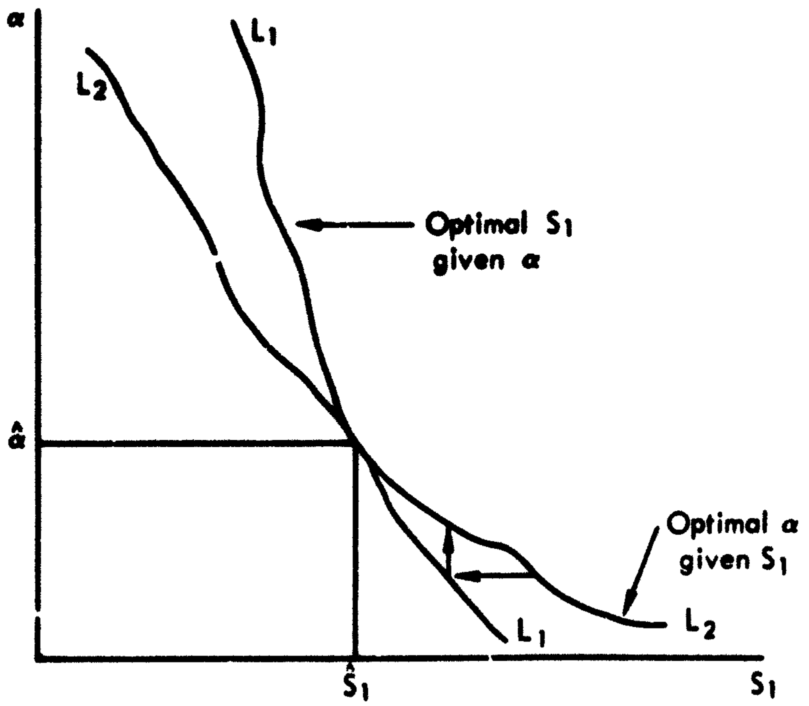
$$\frac{\partial \pi}{\partial \alpha} = C_T \frac{\partial \rho}{\partial \alpha} + (C_T - C_1 - S_1) = 0. \tag{12}$$

This can be restated as:

$$C_T \frac{\partial \rho}{\partial \alpha} = (C_1 + S_1 - C_T), \tag{13}$$

where $C_T \frac{\partial \rho}{\partial \alpha}$ is the marginal revenue associated with an incremental change in α, and is everywhere greater than or equal to zero. Thus equation (13) implies that with α as a decision variable, and given C_T and C_1, the firm will select S_1 so as to yield an expected overrun.

Equations (9) and (13) together determine how S_1 and α will be selected. The interaction of these two relations can be shown graphically by observing that, if second order conditions are satisfied, the slope of the relation showing optimal S_1 given α (which we designate L_1) and the slope of the relation showing optimal α given S_1 (designated L_2) are both negatively sloped, the absolute value of the slope of L_1 exceeds L_2. These relations are shown in the diagram below.



To find the slope of the curve showing optimal values of S_1 given α (that is, the locus L_1), we obtain the total differential of the equation (8) and solve for $dS_1/d\alpha$. Thus we obtain:

$$\left.\frac{dS_1}{d\alpha}\right|_{S_1=\hat{S}} = \sum_{i=2}^{N}\left(\frac{\partial^2 \Psi_i}{\partial S_1^{\,2}} + \frac{\partial^2 \Psi_i}{\partial Z_1^{\,2}}\right) \iota_i < 0$$

Similarly, to find the slope of the curve showing optimal values of α given S_1 (the locus L_2) we take the total differential of equation (12) and solve for the $dS_1/d\alpha$. Here we obtain:

$$\left.\frac{dS_1}{d\alpha}\right|_{\alpha = \hat{\alpha}} = C_T \frac{\partial^2 \rho}{\partial \alpha^2} < 0$$

Second order conditions require that

$$\begin{vmatrix} \pi_{SS} & \pi_{SS} \\ \pi_{\alpha S} & \pi_{\alpha\alpha} \end{vmatrix} > 0,$$

i.e., that $\pi_{SS}\,\pi_{\alpha\alpha} - (\pi_{\alpha S})^2 > 0$. Substituting we have:

$$\left[\sum_{i=2}^{N}\left(\frac{\partial^2 \Psi_i}{\partial S_1^{\,2}} + \frac{\partial^2 \Psi_i}{\partial Z_1^{\,2}}\right)\iota_i\right] \cdot \left[\left(C_T \frac{\partial^2 \rho}{\partial \alpha^2}\right)\right] - (-1)^2 > 0$$

Rearranging, this requires that

$$\frac{1}{\sum\left(\frac{\partial^2 \Psi_i}{\partial S_1^{\,2}} + \frac{\partial^2 \Psi_i}{\partial Z_1^{\,2}}\right)\iota_i} < C_T \frac{\partial^2 \rho}{\partial \alpha^2} \;.$$

But this means that the algebraic value of the slope of L_1 must be less (more negative) than L_2. This is the relation shown.

We can also use the preceding diagram to investigate how a change in the negotiated target cost will affect the choice of optimal S_1 and α. Since there are some complex interaction effects, we will first assume that there is no reputation penalty associated with an overrun, that is, $\frac{\partial \Psi_i}{\partial Z_1} = 0$, for all i.

If the reputation effect is neglected, a decrease in C_T has no influence on the locus L_1 of optimal S_1 given α, but the locus L_2 of optimal α given S_1 is shifted down. Thus the intersection of these two loci $(\hat{S}_1, \hat{\alpha})$ is shifted down and to the right when the negotiated target cost is "tightened up," so that a lower value of $\hat{\alpha}$ and a higher value of $\hat{S}_1$ will be chosen. This last is not an intuitively obvious result.

Taking the reputation effect into account, the locus of optimal S_1 given α will shift to the left as C_T is reduced. With both L_1 and L_2 shifting, the change in the intersection $(\hat{S}_1, \hat{\alpha})$ will depend on the relative magnitudes of the shifts. Unless the reputation effect is quite strong, the responses to a decrease in C_T will be as described above, although our confidence in the proposition that $\hat{S}_1$ will be increased is less than in the proposition that $\hat{\alpha}$ will be decreased.

A UTILITY MAXIMIZING ANALYSIS

The investigation of utility maximizing behavior will proceed in two parts. First, we will introduce an emoluments term into the utility function and examine how these adjust to changing the contractual conditions. Next, we generalize the analysis by introducing operating slack and staff preferences. For this purpose, it is assumed that the utility function is Gossen-type (additive in each of the components).

An Emoluments Model

Before investigating a multiperiod model, we examine a single period model so as to simplify the relations.

The Single Period Model. Designating emoluments by M_1 and current period profits by π_1, we assume that the firm is operated so as to

$$\begin{aligned} &\text{maximize:} \quad U = U[M_1, \pi_1] \\ &\text{subject to:} \quad M_1 \le \bar{M}. \end{aligned} \tag{14}$$

This can be reformulated as a Langrangian. The expression becomes

$$\text{maximize } L(M_1, \lambda) = U[M_1, \pi_1] - \lambda[M_1 - \bar{M}] \tag{14'}$$

substituting $\pi_1 = \rho(\alpha)C_T + \alpha(C_T - C_1 - M_1)$ and assuming that α is specified by the government, C_T is fixed by negotiation, and C_1 is unavoidable cost, we differentiate with respect to M_1 and λ to obtain:*

$$\frac{\partial U}{\partial M_1} = U_1 - \alpha U_2 - \lambda = 0 \tag{15}$$

$$\frac{\partial U}{\partial \lambda} = M_1 - \bar{M} \le 0. \tag{16}$$

If the constraint is redundant, $\lambda = 0$ and $U_1/U_2 = \alpha$. That is, the marginal rate of substitution between profits and emoluments is set equal to the participation rate α. If the constraint is binding, equation (16) is satisfied as an equality ($M_1 = \bar{M}$) and the marginal rate of substitution between profits and emoluments exceeds α.

Assuming that the constraint is redundant we obtain the following expression for the response of M_1 to an increase in α by taking the total differential of (15):

$$\left(\frac{dM_1}{d\alpha}\right)^{o} = \frac{U_2 + \alpha U_{22}\left[C_T \frac{\partial \rho}{\partial \alpha} + \rho \frac{\partial C_T}{\partial \alpha} + (C_T - C_1 - M_1)\right]}{U_{11} - 2\alpha U_{12} + \alpha^2 U_{22}} . \tag{17}$$

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*U_1 is the first partial of U with respect to M_1 and U_2 is the first partial with respect to π_1.

The denominator is negative by second order conditions. Thus the response of M_1 to an increase in α depends on the sign of the numerator. More precisely, since $U_2 > 0$ and $U_{22} < 0$, the sign depends on whether $C_T \frac{\partial\mu}{\partial\alpha} + \rho \frac{\partial C_T}{\partial\alpha} + (C_T - C_1 - M_1) \gtrless 0$. If a large overrun is expected so that the last term in this expression overrides the first two, the entire numerator will be unambiguously positive and M_1 will be reduced in response to an increase in the participation rate, α. If, however, the sum of these three terms is positive (an underrun is expected or the expected overrun is small), the sign of the numerator remains ambiguous so that, on purely qualitative grounds, we are unable to specify the direction of adjustment. We can, however, make the following observations: (a) increasing the value of α will almost surely lead to a reduction in emoluments when target cost has been tightly negotiated ($C_T \leq C_1$) if the increase in the target rate of return (ρ) in response to increasing α is not large and if negotiated target costs are not relaxed as α increases; (b) the change in expenditures on emoluments can go either way if target costs are initially loose or are relaxed as α increases, or if the increase in ρ when α increases is large; (c) very loose target costs and liberal concessions in target rates of return can easily lead to increases in both profits and emoluments as α increases.

The response of M_1 to an increase in C_T has been implicit in our discussion above. It is given explicitly by the expression

$$\left(\frac{dM_1}{dC_T}\right)^o = \frac{U_{22}(\rho + \alpha)}{U_{11} - 2\alpha U_{12} + \alpha^2 U_{22}} \qquad (18)$$

which is unambiguously positive. Thus a decrease in negotiated target

costs necessarily leads to a reduction in expenditures on emoluments. The advantages that inhere in tight bargaining as compared with changing the participation rate should be obvious. However, this is not to dismiss the use of the participation rate as a possible basis for inducing desirable performance. Rather, it is to emphasize that the manipulation of α must be done in conjunction with, not independent of, the negotiation of tight target costs.

The Multiperiod Model. We formulate the utility function by substituting discounted profits for current period profits, so that the objective becomes:*

$$\text{maximize} \quad U = U[M_1, \pi] \tag{19}$$

$$\text{where} \quad \pi = \rho(\alpha)C_T + \alpha(C_T - C_1 - S_1 - M_1) + \sum_{i=2}^{N}(R_i - C_i - S_i - M_i)\iota_i \,.$$

The following first order results are obtained by setting the partial derivatives of U with respect to S_1 and M_1 equal to zero. Thus,

$$U_2\left[-\alpha + \sum_{i=2}^{N}\left(\frac{\partial Y_i}{\partial S_1} + \frac{\partial Y_i}{\partial Z_1}\right)\iota_i\right] = 0 \tag{20}$$

which can be rewritten as:

$$\sum_{i=2}^{N}\left(\frac{\partial Y_i}{\partial S_1} + \frac{\partial Y_i}{\partial Z_1}\right)\iota_i = \alpha, \quad \text{and}$$

$$U_1 + U_2\left[-\alpha + \sum_{i=2}^{N}\frac{\partial Y_i}{\partial Z_1}\iota_i\right] = 0 \tag{21}$$

where this can be rewritten as:

$$U_1/U_2 = \alpha - \sum_{i=2}^{N}\frac{\partial Y_i}{\partial Z_1}\iota_i \,.$$

*For purposes of simplifying the exposition we omit the constraint on the magnitude of emoluments.

Thus we observe that the discounted value of future period benefits resulting from current period investment expenditures are set equal to the current marginal private costs of those expenditures, α, and that the marginal rate of substitution between profits and emoluments is set equal to the sum of the participation rate and the discounted value of the marginal reputation costs associated with an increase in M_1. Comparative statics properties are shown in the tabulation below.

COMPARATIVE STATICS RESPONSES FOR THE MULTI-
PERIOD EMOLUMENTS MODEL

Response Variable	Shift Parameter α	Shift Parameter C_T
M_1^o	?	+
S_1^o	?	+?

These properties reveal that manipulation of the sharing rate is a much less dependable way with which to gain expense control than is the use of tighter target cost -- although this is not to preclude using α in conjunction with C_T to induce desirable performance.

<u>A Generalized Utility Maximization Analysis</u>

In addition to a positive preference for profits and emoluments, we assume that the firm displays a positive preference for staff (S_1) and operating slack V_1, where V_1 is given by

$$\begin{aligned} V_1 &= \text{Actual Operating Cost} - \text{Minimum Operating Cost} \\ &= \frac{1}{1 - v_1} C_1 - C_1 \\ &= \frac{v_1}{1 - v_1} C_1 \end{aligned}$$

where v_1 is the <u>fraction</u> of the work day taken as operating slack.

Thus our utility function becomes:

$$U = U[M_1,\ S_1,\ V_1,\ \hat{\pi}]. \tag{22}$$

To simplify the analysis of comparative statics properties, we assume that the utility function is Gossen-type so that

$$U = f_1(M_1) + f_2(S_1) + f_3(V_1) + f_4(\hat{\pi}) \tag{23}$$

where $\pi = \rho(\alpha)C_T + \alpha(C_T - \frac{C_1}{1-v_1} - S_1 - M_1) + \sum_{i=2}^{N}(R_i - C_i - S_i - M_i)\iota_i$.

Taking the partial derivative of U with respect to M_1, S_1, and v_1 and setting each equal to zero we have:

$$f_1 + f_4\left[-\alpha + \sum_{i=2}^{N} \frac{\partial Y_i}{\partial Z_1}\iota_i\right] = 0 \tag{24}$$

or $$f_1/f_4 = \alpha - \sum_{i=2}^{N} \frac{\partial Y_i}{\partial Z_1}\iota_i$$

which is the same result as we obtained in equation (21) above, and is subject to the same interpretation.

$$f_2 + f_4\left[-\alpha + \sum_{i=2}^{N}\left(\frac{\partial Y_i}{\partial S_1} - \frac{\partial Y_i}{\partial Z_1}\right)\iota_i\right] = 0 \tag{25}$$

or $$\sum_{i=2}^{N}\left(\frac{\partial Y_i}{\partial S_1} + \frac{\partial Y_i}{\partial Z_1}\right)\iota_i = \alpha - f_2/f_4$$

where the expression on the left hand side is the discounted value of the marginal benefits associated with S_1 and U_1/U_2 is the marginal rate of substitution between profits and S_1.

$$f_3\frac{C_1}{(1-v_1)^2} + f_4\left[\frac{-C_1}{(1-v_1)^2} + \sum_{i=2}^{N}\frac{\partial Y_i}{\partial Z_1}\frac{C_1}{(1-v_1)^2}\iota_i\right] = 0 \tag{26}$$

which can be rewritten as

$$f_3/f_4 = \alpha - \sum_{i=2}^{N}\frac{\partial Y_i}{\partial Z_1}\iota_i$$

and we see that the marginal rate of substitution between profits and leisure is set equal to the sum of the participation rate and the discounted value of the reputation costs. Comparative statics responses for this combined U max (Gossen-type) model are shown in the tabulation below.

COMPARATIVE STATICS RESPONSES OF THE COMBINED UTILITY MAXIMIZATION MODEL

Response Variable	Shift Parameter α	C_T
V_1^o	-? (overrun) ? (underrun)	+
S_1^o	?	+?
M_1^o	-? (overrun) ? (underrun)	+

The utility maximization analysis casts doubt on the use of the participation rate to induce either a reduction in expenditures, or a socially optimal level of investment expenditure. Only when tight target costs are negotiated can a reduction in operating slack and emoluments in response to an increase in the participation rate (α) safely be predicted -- and this is conditional on keeping $\frac{\partial \rho}{\partial \alpha}$ and $\frac{\partial C_T}{\partial \alpha}$ small. Moreover, the direction of the adjustment in S_1 remains uncertain (on purely qualitative grounds) whatever the overrun -- underrun situation.

DEFINITION OF TERMS

(a) Discounted profit: π

$$\pi = \sum_{i=1}^{N} (R_i - C_i - S_i - M_i)\delta_i$$

(b) Revenue in period i: R_i

$$R_1 = [1 + \rho(\alpha)]C_T + (1 - \nu)(C_1 + S_1 + M_1 - C_T)$$

$$R_i = \Psi_i(S_{i-1}, S_{i-2}, \ldots S_{i-n}, Z_{i-1}, Z_{i-2}, \ldots Z_{i-n})$$

$$\frac{\partial \Psi_i}{\partial S_{i-k}} > 0; \quad \frac{\partial^2 \Psi_i}{\partial S^2_{i-k}} < 0;$$

$$\frac{\partial \Psi_i}{\partial Z_{i-k}} < 0; \quad \frac{\partial^2 \Psi_i}{\partial Z_{i-k}} < 0;$$

$$\frac{\partial^2 \Psi_i}{\partial S_{i-k} \partial Z_{i-k}} = 0 \text{ (i.e., } \Psi_i \text{ is separable)}$$

$$i = 2, 3, \ldots, N; \quad k = 1, 2, 3, \ldots, N$$

(c) Direct cost in period i: C_i, $i = 2, 3, \ldots, N$

(d) Minimum direct cost in period 1: C_1

(e) Actual direct cost in period 1: $\frac{1}{1 - v_1} C_1$

(f) "Investment" expense in period i: S_i

(g) Expenditures on emoluments in period i: M_i

(h) Discount factor in period i: δ_i

$$\delta_i = \frac{1}{(1 + r)^{i-1}}, \text{ where r is the discount rate}$$

(i) Target rate of return in period 1: $\rho(\alpha)$

$$\frac{\partial \rho}{\partial \alpha} > 0; \quad \frac{\partial^2 \rho}{\partial \alpha^2} < 0$$

DEFINITION OF TERMS (continued)

(j) Target cost in period 1: C_T

$$\frac{\partial C_T}{\partial \alpha} > 0$$

(k) Participation rate in period 1: α

$$0 \le \alpha \le 1$$

(l) Excess of cost over allowable overrun in period i: Z_i

$$Z_1 = \frac{1}{1 - v_1} C_1 + S_1 + M_1 - (1 + \gamma)C_T$$

(m) Fraction of the work day taken as operating slack: v_1

(n) Overrun allowance: γ

(o) Cost variance: σ

(p) Cost of operating slack: V_1

$$V_1 = \frac{v_1}{1 - v_1} C_1$$

Note: Actual operating cost = minimum operating cost + operating slack,

that is, $$\frac{1}{1 - v_1} C_1 = C_1 + \frac{v_1}{1 - v_1} C_1$$